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GEOLOGICAL MAGAZINE

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GEOLOGICAL MAGAZINE

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The Wenlock Strata of South Mayo

By J. G. C. ANDERSON

ABSTRACT

South of Clew Bay, Co. Mayo, Wenlock strata, cut off to the north by a belt of serpentine marking the Highland Boundary, are divisible into three stratigraphical groups. The succession is repeated by a syncline overturned towards the south, which is modified by north-west cross-folds. The Wenlock strata have undergone low-grade "regional" metamorphism, in spite of which fossils have been preserved at a few localities.

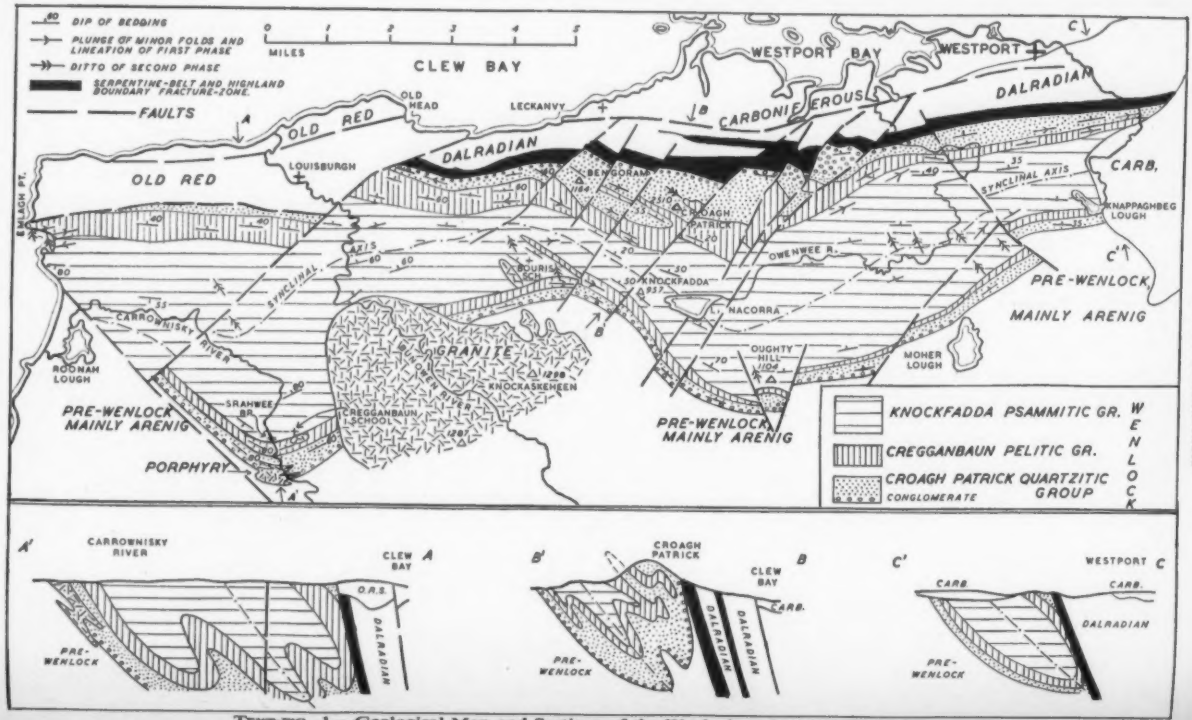
I. INTRODUCTION

THE occurrence of "Upper Silurian" rocks in the Croagh Patrick area, South Mayo, has been known since the publication, between 1870 and 1879, of Sheets 73, 74, 83, and 84 of the Geological Map of Ireland and the appearance of the relevant memoir (Kinahan and others, 1876).

These rocks are limited to the south by a well-marked basal conglomerate, the outcrop of which is interrupted by a lobe of a plutonic intrusion, the Knockaskeheen Granite (Text-fig. 1). To the north they have a faulted boundary, mostly against a belt of serpentine, extending for 12½ miles from Westport to Louisburgh and forming the southern limit of Dalradian metasediments, unconformably overlain by Old Red Sandstone and Carboniferous strata. The latter also unconformably overlap the Silurian to the east.

The serpentine belt has been accepted by several authors (*e.g.* Bailey and Holtedahl, 1938) as the continuation of the Highland Boundary Fracture-zone.

The quartzites and other "Upper Silurian" rocks of Croagh Patrick, south of the serpentine, were stated by Kilroe (1907) to form the inverted limb of an overturned fold. The present paper confirms the existence of this flexure (termed the Croagh Patrick Syncline) and also demonstrates the presence of cross-folds and of a late Silurian "regional" metamorphism. This alteration, although implicit in the older publications, has not been previously described and has not been taken into account in discussions of the structural and metamorphic development of the Caledonides in the British Isles. Finally, the age of the metasediments has been more firmly established by fossil evidence.



TEXT-FIG. 1.—Geological Map and Sections of the Wenlock rocks of South Mayo.

II. Stratigraphy

The stratigraphical succession is as follows :

Knockfadda Psammitic Group.	(top not seen) Green and grey, impure quartzite, fine grit, phyllite partings.	2,000 ft. +
Cregganbaun Pelitic and Calcareous Group.	Calcareous quartzite and flags, sandy limestone and phyllite ; Fossiliferous.	230–1,950 ft.
Croagh Patrick Quartzitic Group.	Quartzite and quartzose grit. Congl. with quartzite and jasper boulders (unconformity).	325–1,600 ft. 0–50 ft.

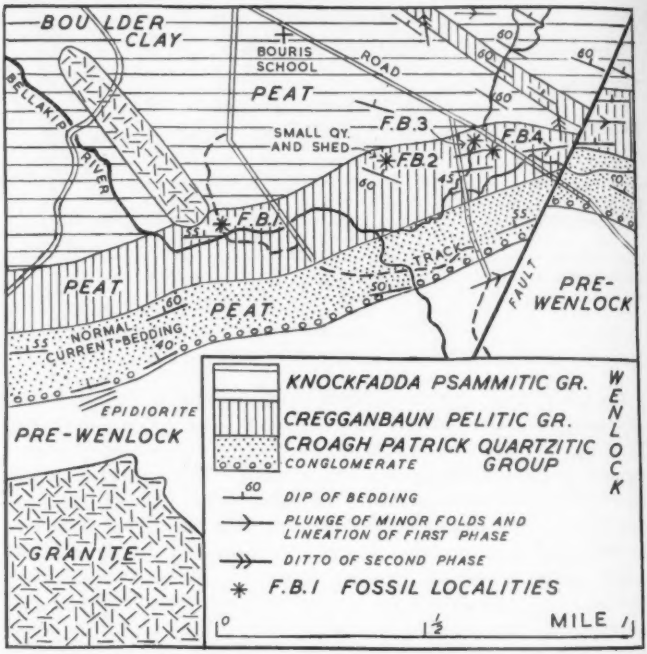
Croagh Patrick Quartzitic Group.—The Quartzitic Group forms conspicuous outcrops along both limbs of the Croagh Patrick Syncline (Text-fig. 1). The basal conglomerate contains very abundant, contiguous, rounded boulders of white quartzite. Many of these are up to 6 inches in maximum diameter, a number up to 1 foot and some up to 1 ft. 6 in. ; the largest boulder discovered was 3 feet long. Boulders of bright-red jasper are also present ; these rarely exceed 6 inches in length and are mostly smaller. In exposures on the southern limb they seldom form more than 1 per cent of the total boulders and in the northern they are even less common. Fragments of other rock-types are very rare ; one pebble was noted of a basic volcanic rock and another of coarse epidiorite.

Although some of the boulders are roughly spherical, most show a conspicuous degree of flattening and are ellipsoidal in form ; the ratio of the maximum to the minimum axis is generally from 3 : 1 to 6 : 1. Some of the quartzite boulders are relatively fine-grained. Others are grits with quartz and some microcline fragments in a granulitized quartzose matrix ; the quartz shows strain-shadows.

The matrix of the conglomerate is relatively sparse and is usually a greenish schist with abundant chlorite ; biotite was noted east of Oughty Hill. Greenish grit forms a fairly persistent bed, about 10 feet thick, on both limbs, between the conglomerate and quartzite.

There is a passage from the conglomerate or green grit into the quartzite. On the south limb this is generally a slightly gritty, greyish rock, which becomes less pure towards the east. In the north limb it is fine-grained, whiter, and on the whole purer.

An unconformable junction between the basal conglomerate and the underlying rocks is exposed at several localities on the southern limb, notably near Cregganbaun, Knockfadda, Lough Gall, and Oughty Hill.



TEXT-FIG. 2.—Geological Map of the Wenlock rocks of the Bouris School area.

For the most part the quartzite rests on slates or phyllites in which sparse Arenig fossils have been found. South of Cregganbaun, however, hornfels immediately beneath the conglomerate has yielded poorly-preserved fossils of probable Llandovery age. These fossils were discovered by Dr. McKerrow (personal communication) who has shown that further south in Connemara a basal Wenlock conglomerate unconformably overlies the Upper Llandovery. It is possible, therefore, that in the present area Llandovery strata intervene in places between a Wenlock conglomerate and Arenig rocks.

East of Moher Lough the conglomerate was not discovered; the field evidence suggests that this is due to thinning out, rather than to lack of exposure.

On the north limb the base of the conglomerate is cut out by the fracture-zone.

Cregganbaun Pelitic and Calcareous Group.—The Croagh Patrick

Quartzite passes through transition beds of thin-bedded quartzites and siliceous phyllites into the Cregganbaun group. Lithologically this shows considerable variation, partly sedimentary, partly metamorphic.

On the south limb fine-grained, fossiliferous hard calcareous flags or impure quartzites with subordinate ferro-calcareous fossiliferous pelitic beds and partings occur in the type locality, fossiliferous impure limestones south of Croagh Patrick and dominantly phyllitic beds still further east.

On the north limb the group has undergone a higher degree of regional metamorphism and consists entirely of silvery, greenish calc-phyllites.

Fossils were recorded from the Cregganbaun area both by the Geological Survey (Kinahan, 1876, p. 22) and by Kilroe (1907, p. 150); and from the Parish of Boheh, south-west of Croagh Patrick by Kilroe (1907, p. 150). In the course of the present work fossils were found at the following localities; many specimens show considerable distortion, particularly those from the Bouris School localities (Text-fig. 2).

FC 1	Small quarry 200 yd. S.W. of Cregganbaun School.	(Mayo 96 S.W.)
FC 2	,, ,, 250 ,, S. 5° W. of ,, ,,	,, ,, ,,
FC 3	,, ,, 600 ,, S. 30° W. of ,, ,,	,, ,, ,,
FC 4	,, ,, 550 ,, S. 3° W. of ,, ,,	,, ,, ,,
FC 5	,, ,, 370 ,, S. of Srahwee Bridge	,, ,, ,,
FC 6	Outcrop in field 335 yd. S. 8° W. of Srahwee Bridge	,, ,, ,,
FC 7	Small crag 450 yd. S. 5° W. of Srahwee Bridge	,, ,, ,,
FB 1	Exposures in track 835 yd. S.S.W. of Bouris School.	(Mayo 96 N.E.)
FB 2	Small quarry 685 yd. S.E. of ,, ,,	,, ,, ,,
FB 3	Stream exposures 730 yd. E. 30° S. of ,, ,,	,, ,, ,,
FB 4	Small quarry 1,000 yd. E. 30° S. of ,, ,,	,, ,, ,,

Kilroe (1907, p. 157) also recorded corals, graptolites, and trilobites from the Cregganbaun Group in the fold west of Croagh Patrick and corals from the antiform to the east. In spite of extensive search the present writer was able to locate only highly sheared corals at both localities.

The fauna (p. 270), in the opinion of Professor A. Williams, is either Upper Llandovery or Wenlock. The only genus which does not completely support this view is *Hesperorthis* which occurs in the Ordovician in Wales and Scotland, but in Sweden ranges to the uppermost Llandovery.

What are almost certainly stratigraphically equivalent strata near Killary Harbour, yielded to McKerrow and Campbell (1960, p. 49) a well-preserved fauna of Wenlock age. The latter date, rather than Upper Llandovery, is, therefore, accepted for the rocks of the present area.

	FC1	FC2	FC3	FC4	FC5	FC6	FC7	FB1	FB2	FB3	FB4
Bumastus sp. ?	—	x	—	—	—	—	—	—	—	—	—
Calymenid pygidium	—	—	—	—	—	—	—	—	x	—	—
Phacopid glabella	—	—	—	x	—	—	—	—	—	—	—
Rhychotreta sp. ?	—	x	—	—	—	—	—	—	—	—	—
Spiriferid ? *Glassia*	—	—	—	x	—	—	—	—	—	—	—
Plectodonta sp. ?	—	x	—	x	—	—	—	—	—	—	—
Atrypa sp. ?	—	—	—	x	—	—	—	—	—	—	—
Leptaena sp. ?	—	—	—	x	—	—	—	—	—	—	—
Hesperorthis sp. ?	—	—	—	—	—	—	—	x	x	x	x
Camarotoechia sp. ?	—	x	—	—	—	—	—	—	—	—	—
Skenidioides	—	x	—	—	—	—	—	—	—	—	—
Streptelasmid corals	x	x	x	x	x	x	x	x	—	x	—
Brachiopod fragments	x	x	x	x	x	—	x	—	—	—	—
Bryozoans	—	—	—	—	—	—	—	x	—	x	—

Knockfadda Psammitic Group.—This consists of fissile, green relatively soft, impure quartzites or grits with phyllitic partings. In places rather harder more massive greyish beds of impure quartzite or siliceous greywacke occur. Much of the group is slightly calcareous and some beds show careous weathering. Near the base of the group, on the southern limb, there is a fairly continuous horizon of relatively pure, white quartzite.

Hornblende-schist and epidiorite.—A number of sills of hornblende-schist and epidiorite occur in the southern limb of the Croagh Patrick Syncline ; they penetrate strata up to the lower part of the Knockfadda Group.

Porphyry.—In the Cregganbaun area acid igneous rocks form numerous intrusions, which are mainly concordant, but which at some localities transgress the bedding of the Ordovician and Silurian strata.

One distinct group of intrusions occurs in the Cregganbaun and Knockfadda Group west of Cregganbaun School. These all form almost perfectly concordant sills, with clean-cut, slightly chilled margins, up to 25 feet in individual thickness ; about six sills in all are present.

To the south a much more continuous mass of porphyry, which seems to form a phacolith fraying out in the sediments to the east and west occurs in the lower part of the Croagh Patrick Quartzite and in the underlying rocks (Text-fig. 1).

III. Structure and Metamorphism

The structural and metamorphic history may be summarized as shown in the table opposite.

Structures of the first (east–west) phase.—The existence of a major fold, with a general east–west trend, is clear from the repetition of the stratigraphical sequence (Text-fig. 1). Current-bedding, indicating a stratigraphical top to the north, was noted at a number of localities

along the southern limb ; the inclination of the foreset beds shows no dominant direction. On the northern limb *inverted* current-bedding, close to the interbedded junction of the quartzite with the structurally underlying Cregganbaun Group, was observed at several localities on the steep west face of Ben Goram, and on the east side of the col, west of Croagh Patrick summit.

Sedimentary or Igneous Event	Structural Event	Metamorphic Event
Deposition of Wenlock sediments.	—	—
Acid and basic minor intrusions.	—	Local thermal metamorphism.
—	Folds of first phase (E.–W. trend)	" Regional " metamorphism with development of primary schistosity.
—	Folds of second phase (N.W. trend)	Slight metamorphism with development of secondary cleavage.
Granite intrusion.	—	Local thermal metamorphism.
—	N.E. and N.W. faulting.	—

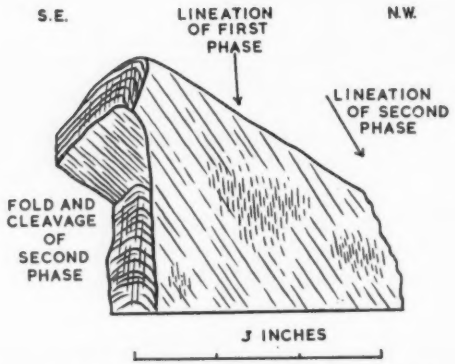
The fold has, therefore, younger rocks in its core, and observations of cleavage and drag-folding on both limbs confirm that it is a true syncline. Other comparatively large folds associated with the first phase are an isoclinal syncline of the Cregganbaun Group within the quartzite west of Croagh Patrick summit and an isoclinal anticline of the same group flanked by the Knockfadda Group south of Ben Goram. Furthermore, the width of outcrop of the latter Group in poorly exposed ground south of Louisburgh, along with the consistent northerly dip, makes it likely that similar isoclinal folding occurs in this area, although not of sufficient amplitude to bring the Cregganbaun Group to the surface.

Minor folds and lineation homoaxial with the Croagh Patrick Syncline are abundantly developed, particularly in the Cregganbaun and Knockfadda Groups. The plunge of these folds is dominantly westerly in the western part of the area and easterly in the eastern, suggesting a culmination near the narrowest part of the syncline, south-west of Ben Goram (Text-fig. 1).

Structures of the second (north-west) phase.—Large-scale evidence of

the second phase of folding is the sinuous nature of the axis of the Croagh Patrick Syncline and of the Serpentine Belt. This is marked by variations in strike of almost 90° both of the first phase folds and of associated b-structures.

Another marked secondary structure is an antiform exposed in the head wall of Lugnademon, the north-east corrie of Croagh Patrick. Much of this wall consists of a dip slope of rusty-weathering, calcareous phyllites passing under the quartzite of the corrie floor to the north. Near the top of the slope, however, these turn over sharply and dip south 10° west at 45° under quartzite forming the ridge. Minor folds pitch east 10° south, but in spite of this quartzite closes over the phyllites



TEXT-FIG. 3.—Sketch of specimen of phyllitic quartzite, showing structures of both first and second phases of folding. Knockfadda Psammitic Group, 1½ miles north of Moher Lough.

to the west on a cliff face north-east of the summit. On lithological grounds and on the presence of sheared corals the phyllites can be referred to the Cregganbaun Group ; they must lie, therefore, in an antiform, which, notwithstanding its slightly anomalous direction, may belong to the second phase of folding.

Further evidence of a phase of cross-flexure is provided by numerous minor folds plunging dominantly, and often fairly steeply, into the north-westerly quadrant, at angles of up to 50°. These are generally less conspicuous than the first-phase structures. In extensive exposures north of Moher Lough, however, minor folds and lineations plunging steeply north-west are dominant. In many cases the lineation of the first phase is still preserved (Text-fig. 3) and can be shown to be folded by the second phase.

Among other localities where both sets of minor structures are well seen, are coastal exposures at Emlagh Point.

Metamorphism connected with the first phase structures.—The Silurian sediments, and particularly the pelitic and semi-pelitic rocks of the Cregganbaun and Knockfadda Groups, show a marked schistosity, parallel to the structures of the first phase, marked by the widespread development of orientated muscovite and chlorite. Apart from the rocks affected by thermal metamorphism (see below), biotite was recorded from only a few localities ; these are too scattered for any attempt to sketch the beginnings of a biotite zone, and in fact the whole region must be regarded as falling within the chlorite zone although possibly near its upper isotherm. The presence of epidote shows that the calcite of the calcareous beds has partly entered into reaction, but in many beds quartz and carbonate co-exist.

The metamorphism is shared by intrusions in the Silurian and by underlying Ordovician rocks. Thus several of the basic intrusions show a strongly schistose structure brought out by alignment of the abundant green hornblende they contain. Of the acid intrusions, the large porphyry mass (see above) is comparatively unaltered. The rock of the thinner sills, however, has a cataclastic groundmass of quartz, turbid felspar, muscovite, chlorite, and epidote with abraded phenocrysts of orthoclase and oligoclase and patches of calcite. A sill from ¾-mile south of Srahwee Bridge is even more altered, and consists of granulitized quartz with streaked out chlorite and muscovite and lenses of calcite ; some larger leucocratic lenses may be augen representing felspar phenocrysts.

Metamorphism connected with the second phase structures.—No marked metamorphism accompanied the second or north-westerly phase of folding, but at many localities there is sharp, small scale puckering of the schistosity planes of the first phase. This is accompanied by the initiation of a new secondary cleavage along the axial planes of these puckers, and the growth of chlorite in the same direction.

Thermal Metamorphism.—As has been shown above, the porphyry intrusions of the Cregganbaun area antedate the regional metamorphism. The pelitic rocks near these intrusions are hornfelses consisting of granoblastic aggregate of quartz, red ferriferous biotite, muscovite, calcite, and pyrite. These rocks have clearly undergone local thermal metamorphism which preceded the regional. In fact, as a result of this earlier alteration, they largely resisted the regional changes, for bedding and current-bedding (in the quartzites) are particularly well-preserved, and the fossils they contain are less distorted than those from localities further west.

South of Croagh Patrick thermal metamorphism in the Cregganbaun

Group is marked by the development of red ferriferous biotite. In this case, the texture suggests it is superimposed on the regional ; it can be ascribed to the Knockaskeheen Granite which has altered pelitic Ordovician rocks to the south to cordierite-andalusite-hornfels and sillimanite-cordierite hornfels.

IV. Faults

The region is cut by a system of north-easterly and north-westerly faults, of which those in the former direction are the more abundant. With two minor exceptions, outcrops are displaced south-westwards on the north-west side of all these north-easterly faults (Text-fig. 1). Since the general structural dip is northerly they could be interpreted as normal or thrust faults all of which overthrow to the north-west. However, the displacement is the same where three north-easterly faults cut vertical strata east of Oughty Hill. It seems more likely that the fractures are transcurrent faults with sinistral displacements. No slickensides were observed. Of the few north-westerly faults which occur, one, cutting the Serpentine Belt, 4½ miles south-west of Westport shows complementary dextral displacement, but another nearer Westport, has a sinstral offset.

It is hoped to discuss the relationship of the Silurian rocks to the serpentine in a later paper, dealing with the Highland Boundary Fracture-zone in Ireland as a whole.

V. Significance of Metamorphism

Although the strata south of the Serpentine Belt of South Mayo have had a polyphase structural and metamorphic history, and are now mostly thoroughly schistose, fossils have been preserved which leave no doubt of their Silurian, almost certainly Wenlock age. Metamorphism, of " regional " type is thus demonstrated to have occurred in late Lower Palaeozoic times in strata belonging to the British Caledonides, analogous to metamorphism of the same age which has been well authenticated in the same orogenic belt in Norway (Holtedahl, 1952, p. 78) and Spitzbergen (Harland 1959, p. 331).

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Seismic Refraction Investigations of the Preglacial Valley of the River Teifi near Cardigan

By Adrian Allen

Abstract

Two short seismic refraction profiles have been shot across the former valley of the River Teifi, above and below Cardigan, with the object of determining the depth to the rock floor. This was found to lie 75 feet below O.D. at Castle Malgwyn, near Llechryd, and 107 feet below O.D. at the present estuary. These figures are consistent with the glacial history of the valley indicated by the geological evidence.

I. Introduction

In preglacial times the River Teifi, which enters Cardigan Bay a few miles below the town of Cardigan, flowed in a wide meandering valley which had been deeply incised in an extensive peneplain. The present and preglacial courses of the lower part of the river are shown in Text-fig. 1.

During the last glaciation which affected this river, a considerable length of the valley was filled with a great depth of glacial deposits. In the process of development of the details of the modern drainage in late-glacial times, short cuts were established in some cases between one meander and another across an intervening spur. Deep narrow rock gorges, ranging in length from a few hundred yards to over three miles, were cut through the spurs.

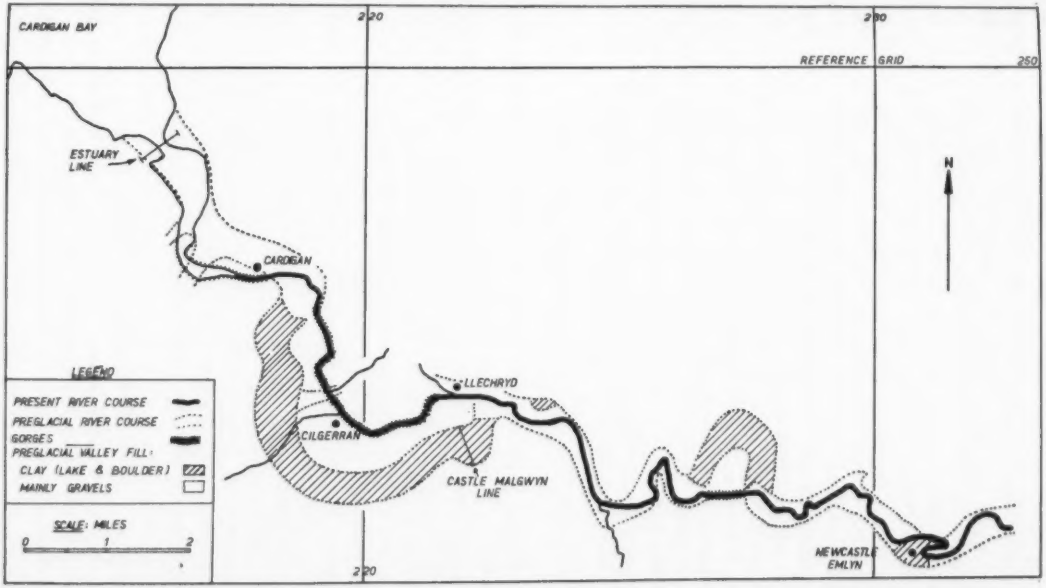
During the excavation of these gorges the level of their rock floors controlled the level of downward erosion in the meanders upstream of their ends.

In the preglacial courses that were abandoned as a result of the short cuts, the glacial valley-fill still largely remains, and even in those reaches that were reoccupied by the river, the fill must still be preserved below approximately the level of the rock floors in the gorges above and below these reaches.

In all the Welsh and Devonshire valleys which have been explored, the pre-glacial rock floors are now deeply buried and, in the lower reaches of the rivers, are well below sea level. Hitherto there has been no investigation of the depth of the rock floor in the preglacial valley of the Teifi, and the purpose of this note is to give the result of a geophysical investigation by the seismic method.

II. Method of Survey and Interpretation

The work was limited to two seismic profiles—one at Castle Malgwyn Farm (about one mile south of Llechryd) and the other across the



TEXT-FIG. 1.—The present and preglacial courses of the River Teifi after an unpublished survey by Professor O. T. Jones.

Teifi Estuary. The locations of the seismic profiles are shown in Text-fig. 1.

A commercial six channel seismic reflection equipment was used, but the refraction method of survey was adopted as the rock floor was expected to lie within a few hundred feet of the surface.

At each site, reversed coverage across the preglacial valley was obtained by firing shots from either end of the profile. The channel is nearly half a mile wide, so that the spread of six geophones at 100 feet intervals was moved several times along the profile. At each spread position, in addition to the main shots, short-range shots were fired at each end of the spread to determine the seismic velocity of the overburden and the thickness of the " weathered " layer. Shot-holes were readily drilled by hand-auger and the sites were seismically quiet.

The Plus-Minus method (Hagedoorn, 1959), which is well suited to the rapid delineation of a shallow refractor of varying dip, was used in interpretation. The addition of the refraction arrival times at any one geophone from shots at each end of the profile gives, after subtraction of the shot-to-shot time and multiplication by a factor involving the velocities, the depth of the refractor under that geophone. That is, depth $= K \times t_{plus}$ where

$$K = 0{\cdot}5\ V_1\ (1 - V_1^2/V_2^2)^{-\frac{1}{2}},$$

V_1 is the valley fill velocity and V_2 the velocity of the valley floor refractor.

The difference of refraction travel times at any one geophone from shots at each end of the profile gives a velocity half that of the refractor when plotted against distance. A plot of these times against distance is known as a " Minus " graph. Such a Minus graph can be drawn using travel times uncorrected for weathering. However, a correction must be applied for the varying dip of the refractor before an accurate refractor velocity can be obtained.

The correction is applied by drawing perpendiculars to the profile of the refractor calculated from the " Plus " times using an approximate refractor velocity. Points on the corrected Minus graph are plotted at the horizontal distance co-ordinate where the perpendicular to the refractor and the refractor meet, instead of at the geophone locations.

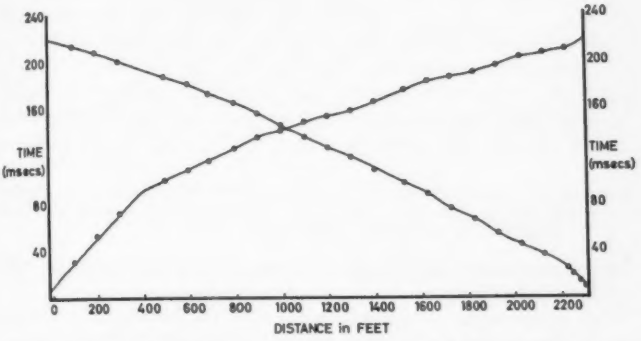
III. Castle Malgwyn Profile

The preglacial valley is here incised into Ordovician slates and infilled with some lake clay underlain by boulder clay.

Time-distance data obtained from shots at either end of the profile are shown in Text-fig. 2. The information from the short-range " weathering " shots is not shown, but gave a weathering thickness over the whole length of the profile of 4 feet, agreeing well with augering

observations. The weathered layer is made up of sun-dried loosely compacted clay and overlies hard blue clay of velocity about 5,000 ft./sec.

The travel times obtained for shots at either end of the profile



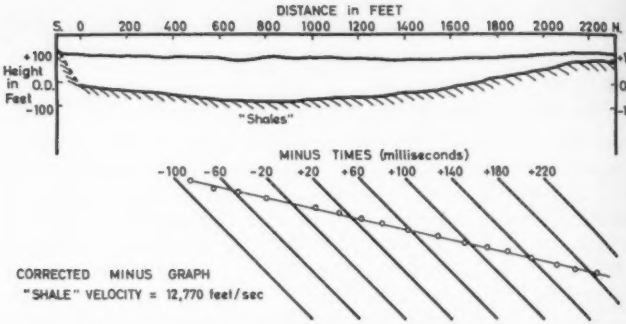
TEXT-FIG. 2.—Time-distance data obtained from the Castle Malgwyn seismic profile.

were first corrected to allow for that part of the travel-time spent in the weathered layer. No refractions were obtained from the lake clay-boulder clay interface, presumably because the velocity contrast was too small.

The valley fill velocity was found to vary over about 650 ft./sec. across the seismic profile, with higher values in the centre of the channel. The depths of the valley floor below the base of weathering datum were found from the " Plus " times where possible : depths under parts of the profile with only one-way refraction coverage were calculated by assuming that the refractor velocity was here the same as that determined by the " reversed " shooting over the greater part of the profile.

The cross-section of the valley floor is shown in Text-fig. 3. The elevation of the lowest point of the floor is 75 feet below O.D.; and the section is markedly asymmetrical, with a steep bluff on the southern side, that is, on the outside of the large meander in the pre-glacial valley shown in Text-fig. 1.

The " Minus " graph is also shown in the figure and indicates a reasonable velocity of 12,800 $\pm$ 200 ft./sec. for the Ordovician slates. The good fit of the points to this straight line is obtained only after the application of the correction for dip mentioned in the previous section, and this is an indication that the interpretation is self-consistent, since



TEXT-FIG. 3.—Interpretation of the time-distance data obtained at Castle Malgwyn. The time axis of the " Minus " graph is oblique to the horizontal distance axis to save space.

the correction itself depends on the form of the cross-section derived from the " Plus " times.

The interpretation is also consistent with the geological evidence, and in view of this consistency and the fact that the Castle Malgwyn site offers nearly ideal conditions for seismic work, it is thought to be reliable.

IV. ESTUARY PROFILE

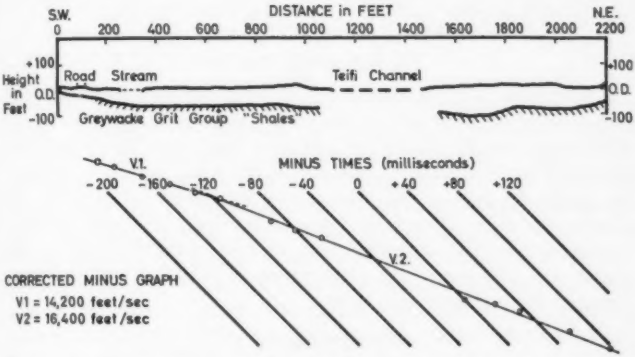
The seismic line across the Teifi Estuary was for the most part shot on dune sand. On the south-west side of the Estuary there is a group of heavy greywacke grits with some dark shales. On the north-east side the rocks are similar to those at Castle Malgwyn. The grit group in the south-west is affected by folds plunging in a north-easterly direction across the estuary at about 20°. All the rocks are Ordovician in age. The grit group passes beneath the " slates " on the north side. The presence of igneous rocks is geologically unlikely.

The valley fill consists mainly of boulder clay, here overlain by dune sand which was dry to a considerable depth. Shallow weathering shots indicated a refractor with a velocity of about 5,000 ft./sec. at an elevation of + 4 feet O.D. This refractor was identified as wet sand : the constant elevation of the refracting interface suggests that the interface is, in fact, the water table. The application of weathering corrections involves the removal of the delay times associated with the dry sand under the geophones, so that the observed arrival times are reduced to times which would be obtained with geophones on a datum 4 feet above sea level.

Examination of the time distance data reveals no refractions from the wet sand/boulder clay interface, probably because of low velocity

contrast and the spacing of the geophone spread. Calculations of Hagedoorn's " K " factor are based upon velocities obtained for the wet sand since no other velocity data are available. It is conceivable that the velocities used for the wet sand might differ by 500 ft./sec., say, from those of the boulder clay which must form the greater part of the valley fill. Such a difference would cause an error in the valley floor depths of approximately 10 per cent.

Depths of the valley floor refractor are determined from the " Plus " times corrected to a datum of + 4 feet O.D. Depths of the valley floor under parts of the profile with only one-way refraction coverage were determined by extrapolation of measured velocities as before.



TEXT-FIG. 4.—Interpretation of the time-distance data obtained in the Teifi Estuary.

The interpretation of the data obtained from the Teifi Estuary profile is shown in Text-fig. 4. The velocities obtained from the corrected " Minus " graph are 14,200 ± 400 ft./sec. for the south-west and 16,400 ± 300 ft./sec. for the north-east part of the profile. It is possible that the velocity change can be identified as a change from the greywacke grit group to the slates, although the velocity of 16,400 ft./sec. for rocks which are apparently similar to those of Castle Malgwyn seems very high. It is conceivable that anisotropy might at least partly account for this discrepancy. The maximum depth of the preglacial valley across the profile is 107 feet below O.D., but this may be subject to a 10 per cent error owing to uncertainties in valley fill velocities and weathering corrections. For these and other reasons the interpretation is thought to be less reliable than that of the Castle Malgwyn profile.

V. Conclusions

It is concluded that the seismic interpretations are on the whole consistent internally, with each other, and with the geological evidence. The results at the two sites indicate a reasonable long profile gradient of between 3 and 6 feet per mile for the preglacial valley. When this gradient is compared with those of the lower reaches of modern British rivers (about 6 ft./mile), it seems most unlikely that the area has suffered a recent east-west tilt of more than about one-tenth of a degree.

The results do indicate a relative rise in sea level since preglacial times, but it is difficult to give an exact figure when the depth of the preglacial river in the estuary is unknown. The relative rise in sea level can, however, be put between the limits of 75 and 107 feet, probably nearer the latter.

VI. Acknowledgments

I would like to thank Professor O. T. Jones for suggesting this work and for making available the results of his unpublished work in the Teifi Valley. Dr. D. H. Griffiths and other members of this department took part in the field work, and Dr. R. F. King helped to prepare the results for publication. The seismic equipment was a gift to the Department from Messrs. Seismograph Services, Ltd., and the Shell Petroleum Company contributed to the cost of the field work. My thanks are also due to the Department of Scientific and Industrial Research for a maintenance grant.

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Mudstone Inclusions in Salopian Conglomerates from County Clare

By J. A. Weir

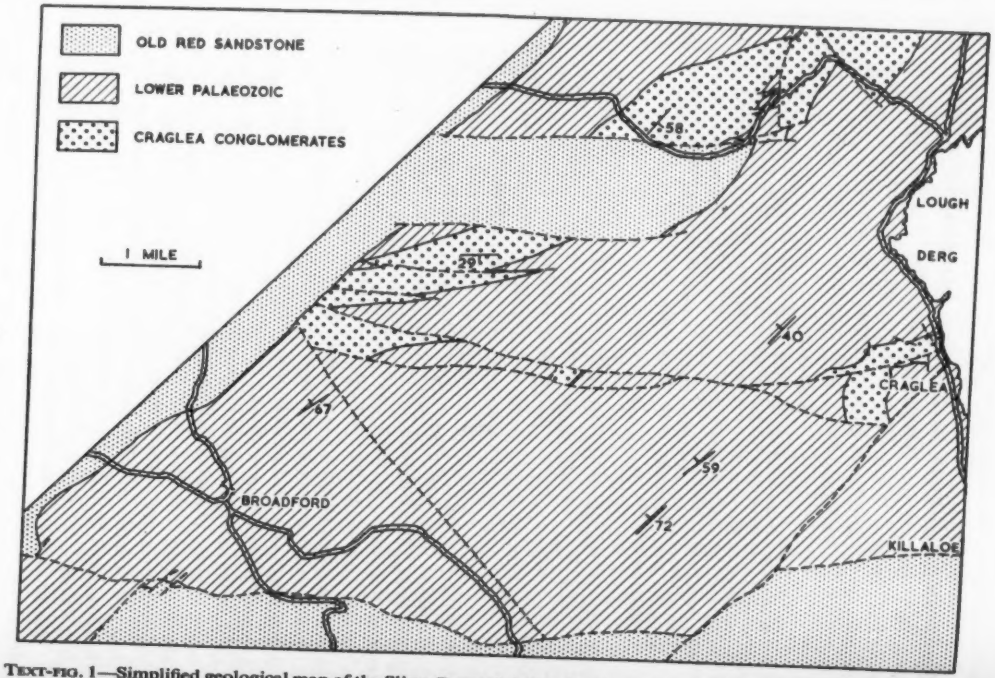
Abstract

Mudstone inclusions in graded greywacke-conglomerates of Salopian age from the Slieve Bernagh Mountains, Co. Clare, are considered to have been formed by fracture of the conglomerates in the course of slumping shortly after deposition and the infilling of the resulting cavities by mud derived from the underlying beds. The attitudes of the inclusions and of associated pebble imbrication suggests that slumping took place on a slope with a northerly inclination of 10°.

The Salopian series of the Slieve Bernagh Mountains consists of a thick succession of sediments of greywacke type which, though dominantly fine in grain, range from mudstones to conglomerates containing pebbles with a maximum diameter of 4 cm. and comprising about 5 per cent. of the total thickness. The conglomerates are distributed sporadically throughout the series, but are mostly concentrated in the upper part, where they make up a 700-foot succession of thick graded beds. This succession is best exposed at Craglea, at the eastern end of the Slieve Bernagh Mountains two miles north of Killaloe (Text-fig. 1), and furnishes a valuable stratigraphical index horizon for which the name Craglea Conglomerates is proposed.

The conglomerates of this group are lithic greywackes as defined by Pettijohn (1957, p. 292, fig. 75), and consist of particles of quartz, fresh felspar and rock fragments in a matrix of fine quartz dust, pale green and faintly pleochroic scales of chlorite and specks of iron ore, together with a variable proportion of secondary ankerite. Rock fragments are abundant and include a wide variety of igneous, metamorphic, and sedimentary types. They display most features of turbidity current deposits (Kuenen and Migliorini 1950). Sorting is absent and most fragments less than 3 mm. in greatest diameter are sub-angular, those larger than 1 cm. being well rounded.

The graded beds in which the conglomerates occur vary in thickness from 2 to 10 metres, the coarseness of the conglomerates being approximately proportional to the thickness of the beds. Complete graded units are exposed in the roadstone quarries alongside the Killaloe-Tuamgraney road at Craglea, where the following divisions are recognizable in the most completely exposed bed :—

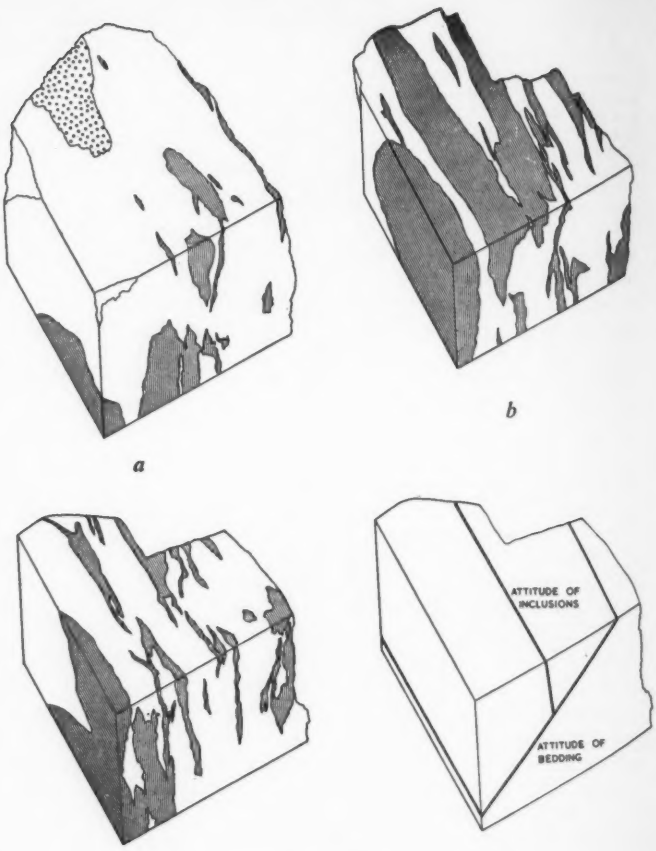


TEXT-FIG. 1—Simplified geological map of the Slieve Bernagh inlier showing outcrops of the Craglea Conglomerates. Mudstone inclusions are limited to the south-eastern outcrop.

	Thickness (in metres)
(Base of succeeding graded bed)	
6. Mudstone with fine siltstone laminae	1
5. Mudstone with small siltstone lenticles	4
4. Coarse sandstone with thin siltstone lenticles . . .	1
3. Conglomerate with 1-cm. pebbles grading upwards into coarse sandstone	3
2. Fine-grained conglomerate with mudstone inclusions .	1
1. Siltstone with fine conglomerate lenticles	0·1
Fine siltstone (top of preceding graded bed)	—

Numerous graded beds are exposed on the adjacent hill of Crag, although none so well as in the quarry. Many have a basal zone of mudstone inclusions; the remainder start as coarse conglomerates which grade upwards into fine grits or coarse sandstones. The tops of the units are rarely exposed.

The mudstone inclusions, which are irregularly lenticular in shape and display a fine concentric banding produced by alternating coarser and finer layers, are arranged approximately parallel to one another and lie with respect to the bedding at angles which vary between 60° and perpendicular, the direction of inclination in any exposure being approximately constant (Text-fig. 2a–c). The very steep attitude of the mudstone inclusions appears to discount formation by normal processes of sedimentation, inclusions produced in this manner tending to lie with their major axes parallel to the bedding or at an angle corresponding to that of pebble imbrication; in the one observed instance of imbricate structure the major axes of the pebbles lie more or less normally to the mudstone inclusions, giving an angle of only 20°. Serial sections through one specimen (Text-fig. 2a–c) show that every inclusion is in contact with one or more of the adjacent inclusions, and through them ultimately with the base of the graded bed. This arrangement recalls the tension cracks produced by slumping of unconsolidated sediments down a plane surface, as in the formation of terracettes (Sharpe, 1938, p. 71, fig. 11c), slumping in this manner resulting in the formation of fissures inclined in the same direction as the slip-plane and opening downwards. The mudstone inclusions may be interpreted as the fillings of such cavities, formed by the slumping of the graded beds in a direction normal to the trend of the inclusions and in the direction of their inclination. The slip planes were furnished by the bedding planes forming the bases of the graded units and were lubricated by the underlying mud. The latter would be in a thixotropic state at the time of deposition of the graded bed, allowing its transformation to a semi-liquid condition when slumping of the conglomerate took place and permitting its injection into the downward-opening cavities formed in the base of the latter. The probability of injection is supported by the concentric banding, which suggests infilling by sediment of

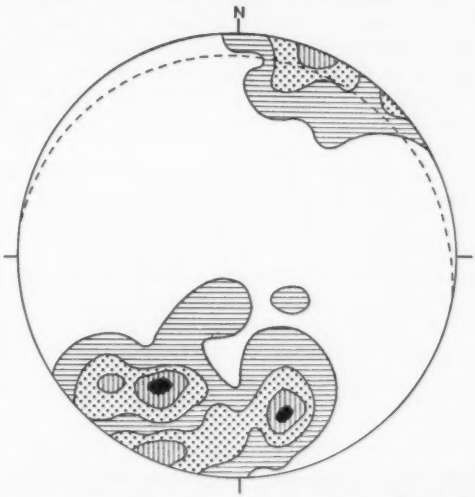


TEXT-FIG. 2—*a*, *b*, *c*, block diagrams of serially-sectioned specimen of conglomerate with mudstone inclusions, ×⅓. Lined ornament—mudstone inclusions; open circles—coarse conglomerate. *d*, comparison of attitude of bedding and mudstone inclusions.

slightly variable composition. In some of the thicker inclusions, banding about two or more centres may indicate a corresponding number of injections, the mud inclusions formed during a previous episode of slumping having become partially consolidated before the resumption of movement, which re-opened the fissures by rupturing

the inclusions or by detaching them from the walls. In the latter case the new infilling is in contact with one of the walls of the fissure. Pressure exerted during the later episode of emplacement has distorted the banding of the earlier infillings, showing that they were incompletely consolidated at that time.

Whereas in most localities the zone of mudstone inclusions appears to rest directly upon the underlying mudstone, in the measured section a thin layer of siltstone containing lenticles of conglomerate intervenes. This layer, representing the basal unit of the graded bed at this locality,



TEXT-FIG. 3—Stereogram of distribution of 120 mudstone inclusions with respect to bedding, the latter rotated to horizontal attitude taking account of superimposed westerly pitch of 14°. Broken line indicates initial slope of modal bedding plane.

was probably deposited locally during an initial swift, subsaturated and erosive phase of the turbidity current which deposited the graded bed. It was evidently welded to the underlying mud firmly enough to resist movement during slumping, remaining in situ to be over-ridden by portions of the slump sheet from farther up-slope, in which the zone of mudstone inclusions is the basal member.

The attitude of the mudstone inclusions relative to the bedding indicates the slope of the floor upon which the beds were deposited. The attitudes of inclusions at 120 localities distributed throughout the group were plotted stereographically and the poles rotated until the associated bedding planes lay horizontally, allowing for a superimposed

westerly pitch of 14°. The poles cluster around two strong maxima on south-south-west and south-south-east azimuths with northerly inclinations of 60° in each case (Text-fig. 3), indicating a corresponding northerly inclination of the basement.

This conclusion is upheld by the occurrence of pebble imbrication noted above, wherein the long axes of the pebbles have a south-south-easterly inclination of 20° relative to the bedding. Long axes of pebbles tend to lie in the direction of the transporting current (Wadell 1936, Schwarzacher, 1951), the pebbles being inclined against the direction of the current, indicating a S.S.W.–N.N.E. flow in this case. White (1952) deduces that the difference between the obtuse bisectrix of the angle between the pebble axes and the bedding (*angle of imbrication*) and the normal to the bedding planes gives the initial slope of the surface of deposition—a north-north-westerly inclination of 10° in this instance. Grabau (1913), postulates slumping on a slope of no more than two degrees.

The evidence available accordingly suggests that the mudstone inclusions represent infillings of tension cracks produced in the conglomerate beds shortly after deposition by slumping down a slope with a northerly inclination.

The writer is indebted to Professor A. Williams, Dr. W. Schwarzacher and Professor Ph. H. Kuenen for their asistance and to the Department of Scientific and Industrial Research for the award of a maintenance grant. The work was carried out in The Queen's University of Belfast in connection with a revision of the Lower Palaeozoic geology of the area.

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Eocene Limestones to the West of Jersey

By Dennis Curry

Abstract

This note records the presence of Eocene limestones *in situ* on the bed of the English Channel along an east–west line to the west of the island of Jersey. The microfauna of samples of these limestones is compared with those of some other beds of similar age. There are comments on the relevance of the above discoveries to the structural history of the area.

Introduction

Geological prospecting in the area of the English Channel immediately to the west of the Channel Islands has until comparatively recently been carried out only by dredging. An account of the most recent work of this kind, together with a summary of earlier observations, is given in Dangeard (1928).

At several stations (marked in Text-fig. 1) Dangeard secured samples which contained abundant fragments of Eocene limestone in small slabs (" plaquettes ") and he deduced that the rocks from which these were derived must be *in situ* very close at hand. At certain other stations he discovered abundant flints complete with the original cortex and he concluded that these were derived from underwater outcrops of Chalk nearby. These stations also are marked in Text-fig. 1. He found no clear evidence of sedimentary rocks other than those of Cretaceous or Eocene age in the area under discussion.

During the course of a voyage from the Channel Islands to Plymouth aboard R.V. *Sarsia* in June, 1955, the opportunity was taken to explore the sea bottom to the west of Jersey. Exploration was carried out with the Hill corer at a series of stations which were spaced about five miles apart on an east–west line approximately at latitude 49° 11′ N. The positions of the stations are illustrated in Text-fig. 1 and listed in Table 1.

Table 1

Station.	*Decca Readings. Chain 5 (English)*			*Approximate Position.*		*Depth (fms.).*
	Red.	*Green.*	*Violet.*	*Latitude.*	*Longitude.*	
378	—	J31·20	F53·14	49° 10′ 10″ N.	2° 37′ 40″ W.	32
379	—	I47·85	F56·00	49° 10′ 50″ N.	2° 43′ 45″ W.	35
380	—	I46·55	F58·77	49° 10′ 55″ N.	2° 49′ 50″ W.	37
381	A3·58	I44·69	F62·68	49° 10′ 50″ N.	2° 59′ 10″ W.	37
382	A3·17	I43·44	F65·08	49° 11′ 40″ N.	3° 04′ 30″ W.	37
383	A2·68	I42·00	F68·05	49° 11′ 45″ N.	3° 11′ 40″ W	39
384	A2·26	I40·55	F71·03	49° 12′ 00″ N.	3° 18′ 40″ W.	40
385	A1·89	I39·20	F73·90	49° 12′ 10″ N.	3° 26′ 00″ W.	42
386	A1·56	I37·82	F76·79	49° 12′ 20″ N.	3° 33′ 50″ W.	45
387	A1·33	I36·68	F79·04	49° 12′ 30″ N.	3° 39′ 20″ W.	47
388	A1·26	I36·15	G50·36	49° 12′ 00″ N.	3° 43′ 30″ W.	48

The following are brief comments on the samples collected:—

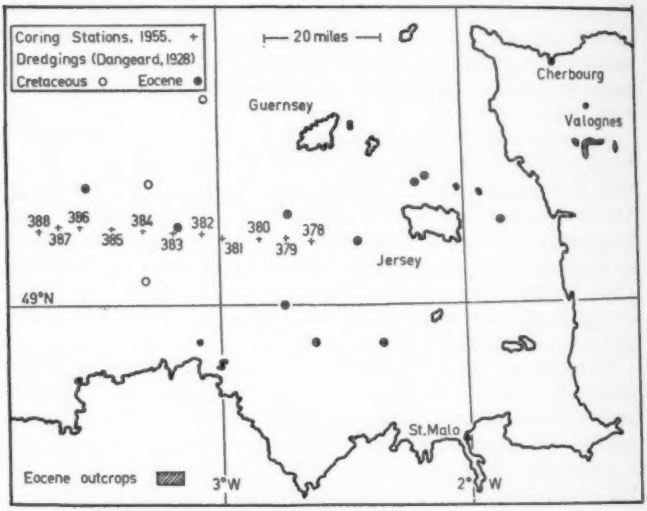
378. Solid rock not reached. Recent sand contained limestone pebbles with miliolids and *Alveolina*.

379. Soft fine-grained buff limestone. *In situ*.

380. Hard cream limestone crammed with miliolids. *In situ* at two adjacent stations.

381. Soft cream limestone. *In situ*.

382. Crumbly pale-buff limestone composed of coarse organic fragments with little interstitial material. *In situ*.



TEXT-FIG. 1.—Map of area to the west of Jersey showing location of coring and dredging stations.

383. Moderately hard cream limestone; coarse textured, with many mineralized organic fragments. *In situ*.

384. A small amount of soft cream limestone on inner and outer faces of coring tool. Rich in microfossils. Probably *in situ*.

385. Soft rubbly white limestone, rich in microfossils. *In situ*.

386. Soft cream limestone on inner and outer faces of coring tool at two adjacent stations. Probably *in situ*.

387. Soft cream limestone on inner and outer faces of coring tool. Probably *in situ*.

388. Fairly hard buff limestone with fragments of *Chlamys* and of echinoderms, moulds of gastropods and lamellibranchs, and many foraminifera. *In situ.*

All the stations thus yielded evidence of the presence of limestone. At all stations except 378 this was certainly or probably *in situ*. The limestones were of a similar lithological type, containing very little detrital material and a high proportion of constituents which were clearly of organic origin. Most samples were rich in foraminifera, while polyzoa, ostracods, and fragments of echinoderms were commonly present. The samples varied considerably in their degree of compaction or cementing, and thus in their hardness, and also in their average grain size. There was also great variation in the extent of the mineralization of the constituent grains. In samples 379 and 385, for instance, details of the ornament of small foraminifera were well seen. In sample 383, on the other hand, equally fossiliferous, the contained fossils were so overgrown with secondary calcite that even generic determinations could not be made with confidence.

Methods of Study of Samples

The largest amount of material available from any station was not more than 500 gm., the smallest, only 10 gm. or so.

The following procedure was followed in examining each sample for fossils. The surfaces of all the larger fragments were first searched. Then a portion of the rock was tested by crushing. In the case of samples 380A and 380B the matrix proved to be as hard as the contained fossils so that it broke at random. These samples were broken into small pieces and all surfaces were searched.

In the case of all the other samples the crush test tended to reduce the rock to its original constituent grains. Each of these samples was treated as follows. The sample was examined and fragments were picked from it which appeared to be unweathered and free from attack by recent marine organisms. It was usually possible to select about half the sample in this way. Each fragment was examined for contamination by recent sand, which was scraped off. The selected fragments were crushed gently and the crushed material was then kneaded under water in a silk cloth with about 140 threads per inch. Kneading continued until no more material passed through the cloth. The retained residue was then dried and examined under a binocular microscope. Material which had been treated as above proved to contain many whole or fragmentary microfossils. Of these, foraminifera and polyzoa were the most abundant of the forms showing good taxonomic characters. Ostracods, brachiopods, and mollusca were also present, but were not common.

Notes on Fossils Discovered

(*a*) *Foraminifera*

Samples 380A and 380B

Rock fragments were seen to be full of foraminifera of individuals belonging to the *Miliolidae*, amongst which the genera *Quinqueloculina*, *Triloculina*, and *Pyrgo* were recognized. There were also a few specimens of *Alveolina* and *Orbitolites*, the characteristic internal structures of which were clearly visible on fracture-sections.

The genus *Alveolina* is believed to be confined to Palaeocene and Eocene beds, while *Orbitolites* is exclusively Eocene (Glaessner, 1945, pp. 120, 122).

Four species of *Alveolina* are recorded from the area which includes England, Belgium, and the northern half of France. *A. oblonga* d'Orbigny occurs in the Sables de Cuise (Cuisian, Paris Basin); also (as a derivative) in the Calcaire Grossier Inférieur (Lower Lutetian, Paris Basin). *A. boscii* d'Orbigny is found in the Calcaire Grossier Moyen (Upper Lutetian, Paris Basin). *A. elongata* d'Orbigny occurs in Lutetian or Auversian beds in the departments of Manche and Loire-Inférieure (N.-W. France). *A. fusiformis* J. de C. Sowerby is found in the Hampshire Basin (Fisher, 1862, pp. 70, 74) in Auversian beds. *A. fusiformis* is probably a synonym of *A. elongata*, and, according to Osimo (1909, p. 87), *A. elongata* is only a variety of *A. boscii*.

The few fragmentary specimens of *Alveolina* found in samples 380A, 380B cannot be assigned confidently to any particular species, though one of them has the fusiform shape associated with *A. boscii* and *A. elongata*.

One species of *Orbitolites* (*O. complanatus* Lamarck) occurs in our area. In the Paris Basin it characterises the higher part of the Lutetian (Abrard, 1925, pp. 202, 302). In Belgium it occurs in beds of Laekenian and Wemmelian age. In England it has been recorded only from Fisher Beds 21 and 22 (Auversian) at Selsey.

Alveolina and *Orbitolites* have only been recorded together in North-Western Europe in beds of Lutetian or Auversian age. It thus seems probable that samples 380A and 380B are either Lutetian or Auversian in age.

Samples other than 380A and 380B

An examination of the foraminifera suggested that the samples are of approximately the same age and the presence of the genera *Linderina* and *Fabiania*, with *Rotalia trochidiformis* and *Eorupertia magna* indicated that this age is probably Middle Eocene. The richest fauna, comprising about thirty species, was found in sample 385. This

foraminiferal fauna is compared below with that of certain other English and French beds of Middle Eocene age.

Fauna of sample 385

It compares most closely with that of three other areas and horizons. These are the Calcaire Grossier Moyen (Upper Lutetian) of the Paris Basin, Fisher Beds 21, 22 (Auversian) of Selsey, Sussex, and the Faluns à Cérithes (Auversian and/or Lutetian) of the neighbourhood of Valognes, Manche (Cotentin, France). It has also several elements in common with faunas in my possession from San Giovanni Ilarione (Upper Lutetian, Vicentino, Italy), and St. Barthélemy (Upper Lutetian or Auversian, Landes, France).

The fauna of sample 385 has been compared with microfaunas from all the major stratigraphical divisions of the Eocene of England and the Paris Basin, and with that of the Sables de Wemmel in Belgium. There is little in common with any of these except with the horizons already mentioned.

TABLE 2.—COMPARISON OF FORAMINIFERAL FAUNA OF SAMPLE 385 WITH THAT OF SELECTED OTHER FORMATIONS

	385	*Calcaire Grossier Moyen.*	*Fisher, Beds* 21, 22.	*Faluns à Cérithes.*
Valvulina triedra Le Calvez	c	f	–	c
Clavulina parisiensis d'Orbigny	r	f	?	f
Discorbis perplexa Le Calvez	r	f	–	–
quadrata (Terquem)	a	r	f	f
Epistomaria semimarginata d'Orbigny	a	f	f	a
Cyclocloculina punctata (Terquem)	(cf.) r	r	(cf.) f	–
Alabamina polygona (Le Calvez)	c	r	–	c
Cibicides robustus Le Calvez	r	f	–	r
Linderina brugesii Schlumberger	a	r	f	a
Fabiania cassis (Oppenheim)	c	r	r	r
Sphaerogypsina sp.	a	r	–	–
Eorupertia magna (Le Calvez)	a	f	f	c
Rotalia audouini d'Orbigny	c	f	c	f
guerini d'Orbigny	(cf.) r	c	c	f
suessonensis d'Orbigny	a	a	f	c
trochidiformis (Lamarck)	a	c	c	a
Amphistegina nucleata (Terquem)	c	r	–	c
Approximate number of other species known	15	220	80	80

a = abundant, c = common, f = frequent, r = rare.

The records from the Calcaire Grossier Moyen in the above table are based for the most part on Le Calvez (1947–1952). Records of *Linderina brugesii*, *Fabiania cassis*, and *Sphaerogypsina* sp. from the Calcaire Grossier Moyen are based on my own collecting at Chaumont-en-Vexin (Oise). All other records in the table are based on my own collecting.

Fauna of sample 385. Notes on some listed species.

Linderina brugesii. Smout (1954, p. 82) says of this species "very widespread in the Middle Eocene of Europe, Africa, India, and the Middle East; also described from the Upper Eocene of Europe". In North-West Europe it is known from the formations mentioned in the table and also from the Sables de Beauchamp (Auversian) of Ver and the Sables de Cresnes (Marinesian; equals Bartonian of English authors) of Quoniam; both of the Paris Basin.

Fabiania cassis. This species was originally described (as a gastropod) from the Middle Eocene of Zovencedo and Roncà, Italy. Silvestri (1926) recognized that it is a foraminifer and created the genus *Fabiania* to receive it. He stated that it is peculiar to the Lutetian and Auversian. Other species of *Fabiania* are recorded from the Eocene of Cuba and the Marianas Islands, and the Middle to Upper Eocene of India.

Eorupertia magna. Glaessner and Wade (1959, p. 205) state that *Eorupertia* is known from the late Lower Eocene of France, Middle Eocene of France, Austria, Turkey, Iraq, Israel, and Oman, from the Middle to Upper Eocene of Assam, Western Australia, West Pacific, New Caledonia, the Upper Eocene of the Alps, Carpathians, and Venezuela; also from the Eocene of Italy. In North-West Europe *E. magna* is known to me only from the formations mentioned in Table 2.

Rotalia suessonensis. In addition to the occurrences noted in the table, the species has been recorded from the Sables de Cuise where, however, it appears to be rare.

Rotalia trochidiformis. Recorded from the Maestrichtian of Holland and Western France (Séronie-Vivien, 1958, p. 130), and the Montian of France (Marie in Marlière, 1959, p. 758). In the Eocene of the Anglo-Franco-Belgian Basin it is known to me only from the formations mentioned in the table, in all of which it is common.

It will be seen that the foraminifera provide two lines of evidence relating to the age of sample 385. Firstly, the genera *Linderina*, *Eorupertia*, and *Fabiania* are found in association in the Tethys in Eocene and especially in Middle Eocene times. Secondly, the fauna of sample 385 can be matched most closely in England and Northern France in beds which are known to be either Lutetian or Auversian in age.

Samples 379, 381, 382, 384, 386, 388

The relationships between the foraminiferal faunas of the above samples and that of sample 385 are shown in Table 3.

It will be noted that every sample contains at least one of the foraminiferal species which are considered to be stratigraphically significant in sample 385. At the same time, nothing was seen in any

TABLE 3.—SOME EOCENE FORAMINIFERAL FAUNAS FROM THE ENGLISH CHANNEL

Station:	379	381	382	384	385	386	388
Valvulina triedra	?	x	–	x	x	x	?
Valvulammina globularis (d'Orbigny)	?	–	–	x	?	x	?
Miliola saxorum Lamarck	x	–	x	–	–	–	–
Pyrgo cf. *bulloides* (d'Orbigny)	x	–	–	x	x	x	x
Alveolina sp.	x	–	–	x	–	x	–
Discorbis perplexa	x	–	–	–	x	–	–
quadrata	x	–	–	–	x	–	–
Epistomaria semimarginata	x	–	–	x	x	x	x
Cycloloculina cf. *punctata*	x	–	–	–	x	–	–
Alabamina polygona	x	x	–	–	x	–	–
Cibicides robustus	–	?	x	–	x	–	–
Linderina brugesii	x	x	–	–	x	–	–
Fabiania cassis	–	–	x	–	x	–	–
Eorupertia magna	–	–	x	–	x	x	x
Rotalia cf. *complanata* d'Orbigny	–	–	–	x	–	x	x
suessonensis	x	–	x	?	x	x	–
trochidiformis	x	–	x	x	x	x	–
Amphistegina nucleata	x	–	–	?	x	–	–
Additional species not listed above	11	4	3	7	18	4	10

sample which suggested that it is likely to be of a different age from the others. The presence of *Alveolina* in three of the samples, linking this group with samples 380A and 380B should also be noted. I conclude therefore that the samples in this group are also of Lutetian or Auversian age.

(*b*) *Ostracods*

Most of the samples contained a few ostracods. These are for the most part paired valves and their ornament has commonly been obscured by secondary calcareous material. The only sample which contained valves in a good state of preservation was 379. About twenty of these were isolated. The following forms appear to be represented: *Bairdoppilata gliberti* Keij, *Haplocytheridea* aff. *perforata* (Roemer), *Aulocytheridea* sp., *Brachycythere ventricosa* (Bosquet), *Cytheretta concinna* Triebel, *Schizocythere tessellata* (Bosquet), and *Bradleya kaasschieteri* Keij.

What appeared to be *Bairdoppilata gliberti* was present in several other samples, while unidentified species of *Leguminocythereis*, *Echinocythereis* (?), and *Quadracythere* (?) were also noted in these.

The ostracod fauna mentioned above does not provide a very precise indication of age. It could, however, be said to be probably Eocene. At the same time it appears to contain nothing which cannot be matched among known ostracod faunas of Middle or Upper Eocene age in the Anglo-Franco-Belgian Basin.

(*c*) *Brachiopods*

Sample 385 contained fragments and juveniles of about twenty brachiopods. Mr. G. F. Elliott has very kindly reported on these as

follows. There are ten specimens of an *Argyrotheca* which is, he believes, *A. decemcostata* (Deshayes) of the Lutetian of the Paris Basin. The remainder of the specimens are of *Terebratulina* of two species. Two complete specimens are referred by Mr. Elliott to *T. squamulosa* (Baudon), also from the Lutetian of the Paris Basin. Another specimen, a juvenile, may be *T.* (*Eucalathis*) *morelleti* Elliott, which is extremely rare in the Auversian of the Paris Basin.

(*d*) *Polyzoa*

Most of the samples contained polyzoa and one (385) was rich in these. No attempt has been made to study them in detail, but species of the following genera were seen to be present in sample 385: *Crisia, Crisisina* (?), *Hornera, Exochoecia* (?), *Vincularia, Nellia, Poricellaria, Tubucella, Escharoides* (?). Many of the species appeared to be identical with forms from the Middle Eocene of the Paris Basin and the Cotentin described by Canu (1907–1910).

(*e*) *Mollusca*

No fossils of aragonite were seen to be preserved in any sample, so that it is not surprising that remains of mollusca are rare. However, a few indeterminate moulds of small gastropods were found, and sample 388 contained an unidentifiable fragment of *Chlamys*.

(*f*) *General*

It has already been stated that the evidence provided by the foraminifera points to a Lutetian or Auversian age for the samples from stations 379, 380, 381, 382, 384, 385, 386, and 388. The evidence from the groups other than the foraminifera is in no way inconsistent with this conclusion.

Samples 378, 383, and 387

No attempt was made to name the heavily mineralized fossils present in samples 383 and 387. The lithology of these two samples was similar to that of neighbouring samples and they are provisionally assumed to be of the same age as the latter.

Sample 378 was of recent sand and gravel which contained pebbles of limestone with miliolids and *Alveolina*. In view of the existence of Eocene beds *in situ* at station 379, less than five miles away, no additional conclusions can safely be drawn from sample 378.

Summary and Conclusions

The examination of the series of samples from stations 378 to 388 inclusive has established beyond doubt the existence of a considerable area of rocks of Lutetian or Auversian age in the Gulf of St. Malo.

This finding confirms the observations of Dangeard (1928, pp. 133–148) who, as already stated, dredged limestones with Eocene fossils from several stations in this area.

The samples here described are closely similar both in lithology and fauna to the Faluns à Cérithes of the Cotentin peninsula. These latter beds consist of accumulations of organic remains which contain little detrital material and which display all variations in hardness between incoherent calcareous sands on the one hand and compact limestones on the other. The Faluns à Cérithes occur in shallow basins in the main massif of the Palaeozoic and early Mesozoic rocks of the peninsula where they rest with unconformity and overlap on thin beds of Cenomanian and Maestrichtian age. The Faluns à Cérithes have a maximum thickness which has been estimated at 120 feet. They are everywhere rich in foraminifera. In addition, at certain localities they have yielded a rich molluscan fauna which includes a high proportion of individuals and species of gastropods of rock- or seaweed-haunting types. Corals, echinoids, and calcareous algae are also present, the whole indicating shallow open sea conditions.

It seems probable that in Middle Eocene times the older rocks of the Cotentin peninsula with their undulating surface formed a series of islands or shoals around and among which the Faluns à Cérithes were deposited.

Dangeard recorded Eocene marine limestones from the sea bed between Guernsey and Jersey and between Jersey and the mainland of France. On the basis of these and other observations he concluded (1928, p. 146) that " l'aspect que présentait cette région au Lutétien devait ressembler à celui qu'elle présente actuellement: en effet, les îles anglo-normandes d'alors étaient entourées par la mer . . . la dépression du golfe normano-breton existait donc déjà à l'Eocène . . .".

The extent over which Lutetian or Auversian rocks have been proved is now so great that it may reasonably be concluded that they are horizontal or nearly so. One may note too that they are now in about the same position with respect to sea level as they were when they were originally deposited.

Materials described in this paper are housed in the collection of the Geological Survey and Museum, London, under reference numbers MR22584 to MR22595 inclusive.

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EASTBURY GRANGE,
WATFORD ROAD,
NORTHWOOD, MIDDLESEX.

The Permian and Trias of the Oman Peninsula, Arabia

By R. G. S. Hudson

(PLATE IX)

Abstract

The lower part of the limestone succession of the Hagab Monocline in the Oman Peninsula, Arabia, is divided into the Bih Dolomite (Permian, 650 m.), Hagil Limestone (Permian, 260 m.), Ghail Limestone (Trias, 600 m.), and the Elphinstone Beds (Noric, 431 m.). The latter consists of five formations, two of which are very fossiliferous. The succession also occurs to the south in borings in the forelands of the Oman Mountains and is similar to that of the foreland of the Zagros Range of Iran.

Introduction

The Oman Peninsula (Ruus al Jibal) consists of a series of upthrust blocks of Permian to Lower Cretaceous strata. One of these, on the east side of the peninsula opposite Ras al Khaima and dominated by Jebel Hagab, is monoclinally folded and deeply eroded. Two geological reconnaissance field parties of the Iraq Petroleum Company worked in this area in January and February of 1951 and 1952, the first party consisting of R. V. Browne, Z. R. Beydoun and the author, the second of D. M. Morton, E. Shaw, A. McGugan, and the author. M. Chatton later examined thin sections of the rock samples collected and identified the foraminifera, G. F. Elliott named the calcareous algae, and R. P. S. Jefferies and the author named the brachiopods and lamellibranchs of the Asfar and Sumra formations. The structure of the area was described in 1954 by Hudson, McGugan, and Morton, and the Jurassic and Lower Cretaceous stratigraphy of the Musandam Limestone by Hudson and Chatton in 1959. The remainder of the succession, of Permian and Triassic age, is described in this paper. These beds were also encountered in the Fahud Boring where the succession was observed and compiled by P. Walmsley.

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General Stratigraphy and Structure

The total thickness of strata exposed in the Oman Peninsula is about 3,400 m. Of this Lees (1928) gave a general account of the upper 1,810 m. which he divided and aged as follows:—

Musandam Limestone (Jurassic to Lower Cretaceous)	1,415 m.
Elphinstone Beds (Upper Trias, probably Noric) .	151 m.
Unnamed (? Permian)	244 m.

The lowest 244 m., described from the Elphinstone Inlet, are now known to be Upper Trias in age and were named the Milaha Limestone

(Hudson *et al.*, 1954): since their lithology is similar to the Elphinstone Beds this stratigraphical group is here extended downwards to include them. The 1,600 m. of limestone and dolomite found to occur below the strata recorded by Lees were divided and named the Bih Dolomite, Hagil Limestone, and Ghail Limestone (Hudson *et al.*, 1954). The major divisions of the succession are now considered to be as follows:—

Musandam Limestone (Rhaetic to Lower Cretaceous)	1,475 m.
Elphinstone Limestones with Sandstones and Marls (Noric)	431 m.
Bih, Hagil, and Ghail Limestones and Dolomites (Permian and Trias)	1,506 m.

This threefold grouping of the succession is the dominant feature of the geology of the area. It can be recognized from the air, from air photos, and from a considerable distance on the ground. The three divisions are considered to stratigraphically rank as " groups ". The Musandam Limestone and the Bih to Ghail Limestones and Dolomites are insufficiently known and are not therefore divided into formations. The lithological succession of the Elphinstone Group is well established and is divided into the following formations, well recognizable in the field:—

Shuba Limestone and Marl (field name: Upper Brown Beds)	64 m.
Sakhra Limestone (field name: Middle Limestone)	23 m.
Sumra Limestone and Marl (field name: Lower Brown Beds)	56 m.
Asfal Limestone, Marl, and Sandstone (field name: Lower Brown Beds)	108 m.
Milaha Limestone (field name: Lower Grey Beds and *Megalodon* Beds)	180 m.

Sections Sampled.—The outcrop of the Bih Dolomite which occupies the core of the Hagab Fold consists of a number of steeply dipping N.–S. folds (see geological map, Hudson *et al.*, 1954, pl. 8). It was not possible to examine the central part of this outcrop so it is possible that there are lower beds exposed than those here recorded. Moreover, since the entire structure is an overthrust one, sections end at the thrust junction at different levels. The main section measured is that on the east side of Wadi Bih. It commences at the head of Wadi Siyat where the lowest beds, a few feet of sandstone below the apparent base of the Bih Dolomite, are exposed, and continues to where the Ghail–Bih embayment turns east. Its earlier part is a slowly changing strike section; its latter part is across the southern plunge of the Hagab Fold and therefore a dip section. The beds thus measured include the Bih Dolomite, the Hagil Limestone, and the lowest part of the Ghail Limestone. The remainder of the Ghail Limestone was measured on the south side of the Bih–Ghail embayment eastwards to its junction with the Milaha Limestone.

The Elphinstone Group was for the most part measured and sampled in Wadi Milaha which crosses the southern plunging end of the Hagab Monocline. The lowest beds exposed, the *Megalodon* Beds, occur at the axis of the structure about 2 km. up the wadi. The measured section commenced here and continued eastward to the junction of the Elphinstone Group and the Musandam Limestone, high on the south side of the wadi above the Hubous shelters. The lowest 115 m. of the Milaha Limestone was measured on the south side of the Ghail–Bih entrance embayment.

The thicknesses given are the result of measurement of individual beds carried out once on steeply dipping sections, often near-strike sections and, as such, they may be considerably in error. So far as is known no strata older than the Bih Dolomite outcrop in the Peninsula nor are strata newer than the Musandam Limestone ever preserved except along the mountain front and in the J. Hagab window below the thrust (Hudson *et al.*, 1954).*

The dominant structures in the Peninsula are N.–S. arcuate thrust faults, associated tear faults, and N.–S. folds. There is a slight regional northwards dip so that in the south the Bih to Hagil Series are the principal outcropping beds with the Musandam Limestone capping such heights as J. Hagab (1,500 m.), J. Qawa (1,900 m.), and J. Yabana (1,700 m.). In the north outcrops of Musandam Limestone occupy most of the peninsula with the Trias occurring mainly in the core of anticlines, such as the Shaam Anticline, or at the front of upthrusts such as that south of J. Harim (2,100 m.).

Stratigraphical Succession

Bih Dolomites : Permian, c. *650 m.*

These beds consist of grey, medium grained, saccharoidal dolomites, weathering brown, alternating with less common, fine-grained porcellaneous limestones, more or less dolomitized and weathering light brown or light grey: there are also occasional semi-oolitic limestones. Thin level bedding is general though the dolomites may be massive bedded. The uppermost 90 m. of these beds form a consistent marker since they are thin-bedded dark brown-weathering dolomites without the lighter coloured limestones. Another outstanding marker, about 300 m. from the base of the group, consists of about 3 m. of thin-

* In this paper the authors recognize 15 m. of mudstones (Fukhairi Beds, Senonian) and 50 m. of limestones and breccias (Lakshaifa Beds, Aptian-Albian) overlying a thick series of radiolarian cherts and calcite mudstones (Shamal Cherts), all in succession below the overthrusting Bih to Musandam strata. While the Fukhairi and Lakshaifa Beds were considered to be younger in age than the Musandam Limestone, the Shamal Cherts were equated with part of it. The entire succession is now considered to be post-Musandam Limestone.

bedded brecciated porcellaneous limestones weathering almost white. The lithology is otherwise monotonously similar throughout the group.

Though occasional limestones show traces of shell debris and algae are occasionally recognizable, the only age-diagnostic fauna found was in a fragmental semi-oolitic limestone about 155 m. from the base of the group. This contained the foraminifera *Calcitornella*, *Geinitzina postcarbonica* Spandel, *Globivalvulina graeca* Reichel, *Glomospira*, *Hemigordius*, *Pachyphloia* cf. *multiseptata* Lange, *Padangia* cf. *venosa* Lange, *Parafusulina* and other fusulinids, and the algae *Pseudovermiporella sodalica* Elliott and *Anthrocoporella spectabilis* Pia.

Hagil Limestones : Permian, c. *260 m.*

These beds are generally thin and evenly bedded, weathering platy or into slabs. They consist of alternations of grey fine-grained argillaceous limestones, often with shaly partings or very occasionally separated by shales, and dark grey fine-grained limestones which may be dolomitized and weather brown. Occasional beds of semi-oolitic limestones also occur. These usually contain a foraminiferal fauna, variously *Hemigordius*, *Agathammina pusilla* (Geinitz), *Climacammina*, *Glomospira* (common), and cf. *Robuloides*, a fauna considered to be of Permian age. The upper boundary of the limestone is taken at a dark-grey limestone-breccia, 0·5 m. thick, with prominent fragments of light coloured porcellaneous limestone; the lower at the base of a distinctive group of laminated shaly limestones.

Ghail Limestone : Trias, c. *600 m.*

This limestone is formed of more massive beds than the underlying Hagil Limestone and Bih Dolomite and since it is also lithologically distinct from the overlying marly and sandy Elphinstone Limestones which weather back, it is an easily recognized formation. This is the more so since 13 m. from its top there are 25 m. of massive-bedded dolomites usually forming a well marked topographical feature with a steep cliff-front.

The limestone is usually grey in colour, weathering light-grey or, more rarely, buff, cream, or brown. It is fine to medium crystalline, often laminated and often dolomitized. Light-grey porcellaneous limestones also occur and very occasionally there are oolitic-coated fragmental limestones. Calcite aggregates, calcite veining, and geodes are common. Rubbly limestones and solution breccias also occur, the latter between the limestone beds. Cavernous weathering is common and there is also considerable fracturing and buckling and consequent breaking down of the limestones. These features suggest that sedimentation was in an evaporite environment and that beds of anhydrite might be expected in an unweathered section. Marl is absent except in the

middle of the formation where a few thin beds of soft, malachite-green marl occur interbedded with reddish weathering porcellaneous limestones.

Shell debris, ostracods, and algae are common. *Zonotrichites lissavensis* Bornemann, an alga from a semi-oolitic limestone 110 m. from the top of the group, was originally recorded from the Upper Trias of Germany. *Trocholina* was the only foraminifera found in the main part of the limestone though the lowest beds occasionally contain *Hemigordius*, *Agathammina*, *Glomospira*, and *Climacammina*.

The lowest 15 m. of the Ghail Limestone consist of thin-bedded limestones and dolomites with some interbedded marl. The limestones may be porcellaneous or rubbly, weather red-brown or yellow and may be purple-stained: the marl weathers grey-green, greenish-brown, khaki, or yellow. Casts of fossils were not uncommon, but were not collected. Field identification suggest they were Triasic lamellibranchs comparable to *Pseudomonotis* and *Myophoria*. The uppermost 5 m. of limestone is fine-grained, weathering buff and reddish brown: it ends with a thin dark-green shale.

Milaha Limestone : Upper Trias (? Noric), 180 m.

This, the lowest formation of the Elphinstone Group, is very different from the underlying Ghail Limestone since its limestones are usually dark-grey, argillaceous, or sandy, irregularly bedded and rarely dolomitized. Shaly marls and thin sandstones are not uncommon. The formation thus weathers back in contrast to the outstanding Ghail Limestone.

Shell debris, ostracods, crinoids, algae, and bryozoa are common throughout though identifiable fossils have not been collected. *Megalodon* occur abundantly in various limestones in the upper part but were difficult to extract. Foraminifera are represented only by the banal forms *Frondicularia*, *Quinqueloculina*, *Spirillina*, *Trochammina*, and *Trocholina*.

Since passage to the overlying Asfal Beds is transitional, a distinctive feature-forming dark brown to purple sandy ferruginous massive limestone, about 2 m. thick, is taken as an arbitrary upper limit.

The lowest 49 m. of the formation are a distinctive group of thin-bedded limestones with sandstones and sandy marls, which variously weather buff, yellow, or reddish. They all tend to be nodular and rubbly, often conglomeratic, though there are occasionally more massive or flaggy limestones. Cherts occur occasionally and many of the mudstones are siliceous. Above these are 76 m. of well-bedded more massive limestones, shelly, with chert, sometimes dolomitic, and usually weathering light-brown. Several beds crowded with *Megalodon* and other lamellibranchs occur in their upper part and are associated

with nodular limestones. The upper 55 m. of the formation are mainly dark-grey nodular-bedded limestones, weathering grey or, less common, brown, and usually sandy. Brown, yellowish, or grey-green marls and rubbly marly limestones also occur and there is some brown sandstone. The limestones may be massive, thin-bedded, or very irregular, the latter suggesting contemporaneous slumping. Fossil debris is common, occasional marls containing casts of lamellibranchs.

Asfal Limestone, Marl, and Sandstone : Noric, 108 m.

This formation is both lithologically and faunally linked with the overlying Sumra Formation though it is not so fossiliferous nor is the marl so common or so colourful.

Sandstones, often quartzitic, and sandy limestones are the common rocks in the lowest 42 m. In general they and the rare shale, weather reddish or yellowish-brown or even purple. The limestones, sandy, marly, or calcite-mudstones and often rubbly and nodular, weather brown or buff-coloured. Fucoidal structures are common. *Diplopora* is not uncommon, shell-debris may occur, and a limestone near the top contains abundant stromatoporoids.

The next 30 m. are mainly yellow or brown-weathering calcite-mudstones, flaggy argillaceous limestones, and buff or chocolate brown-weathering shaly marls. There are also occasional sandstones. Fossils, mainly lamellibranchs common in the overlying Sumra Formation and numerous *Spiriferina griesbachi* Bittner, are common especially in the lowest 4 m. The uppermost 5 m. and a limestone 4 m. below it, are calcite-mudstones with numerous corals and stromatoporoids. *Diplopora* occurs throughout.

The uppermost 36 m. consists of the following beds (from top downwards):—

Massive feature-forming limestones, mainly mottled purplish calcite-mudstones with interbedded purple shales. Abundant *Lovcenipora* and stromatoporoids .	3 m.
Limestones, mainly grey and thin-bedded, and yellow and red shales. Occasional corals and lamellibranchs . .	9 m.
Grey, massive, nodular limestone	3 m.
Yellow and purple shaly marls and rubbly limestones. Corals	2·5 m.
Fine-grained nodular limestones. *Misolia* common . .	1·5 m.
Purple, red, and yellow shales with interbedded limestones	5 m.
Massive, fine-grained limestone with *Dicerocardium* . .	2 m.
Purple, red, and yellow shales with interbedded shelly and nodular limestones, some conglomeratic . . .	3 m.
Massive, blue-grey limestones with abundant *Dicerocardium*, separated by rubbly limestones with corals .	2 m.

Sumra Limestone and Marl : Noric, 56 m.

Brown flaggy limestones, often rubbly, and purplish-red or yellow marly shales, both with abundant fossils, mainly small lamellibranchs,

from the greater part of this formation. Fine-grained more massive grey limestones also occur and may contain corals and stromatoporoids. The 15 m. of beds, 4 m. from the top of the formation, are mainly greenish-grey marls crowded with *Modiola*, weathering back and thus forming a distinctive feature. The lower 27 m. of the Sumra Beds are crowded with *Lopha blanfordi* (Lees) and can thus be distinguished from the upper 29 m. in which *Modiolus*, *Myophoria*, and *Anodontophora* are the common fossils. *Rhynchonella* cf. *bambanagensis* Bittner, common in the Noric of Spiti, also occurs in these beds. The lamellibranchs of the Sumra Beds are described in a later paper by R. P. S. Jefferies and the author. They include *Modiolus jaworskii* Wanner and Knipscheer, *Modiolus* sp. nov., *Indopecten* cf. *clignetti* (Krumbeck), *Dimyodon* cf. *subrichtofeni* Krumbeck, *Lopha blanfordi* (Lees), *Pseudolimea ?cumaunica* (Bittner), *Costatoria omanica* (Diener), *Palaeocardita trapezoidalis* (Krumbeck), *Anodontophora griesbachi* Bittner, and *Pleuromya himaica* Diener. The corals, mainly *Thecosmilia* and *Thamnasteria*, have not yet been specifically determined.

Sakhra Limestone : ? Trias, 23 m.

This limestone forms a marked feature not only in Wadi Milaha but throughout the Jebel Hagab area and probably in most of the Oman Peninsula. Its limestones are dark-grey, finely and uniformly crystalline, massive, especially at the top, or flaggy, and occasionally semi-oolitic. Shell debris occurs rarely: ostracods occur occasionally.

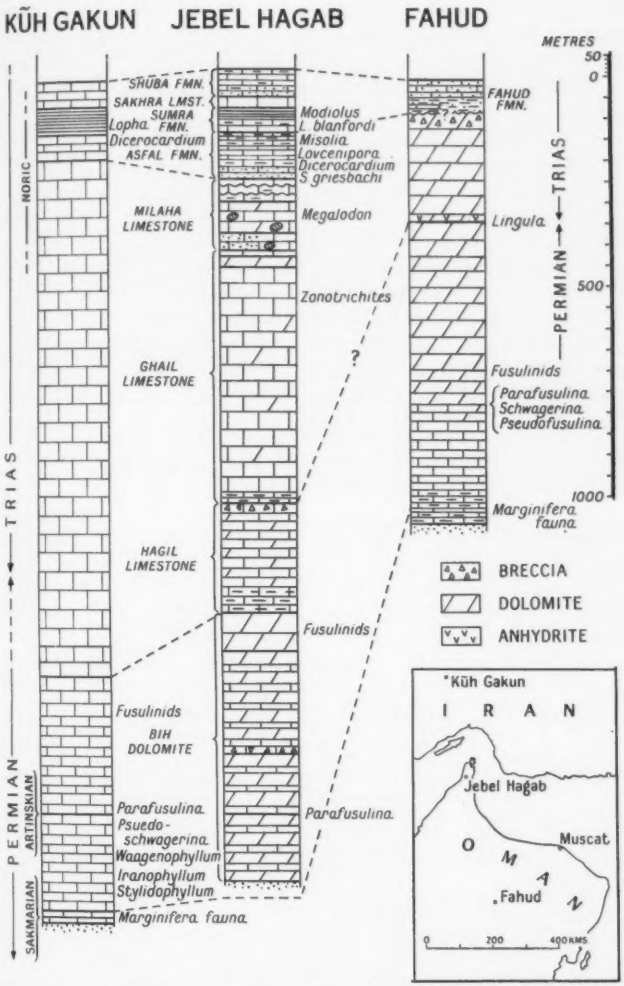
Shuba Limestone and Marl : ? Trias, 64 m.

These limestones, sandstones, and marls weather brown or, less common, yellow or purplish-red and are thus distinct from the overlying grey limestones of the Musandam. The limestones are in general flaggy-bedded calcite-mudstones, often mottled, though occasional massive grey-weathering limestones occur in the lower part of the formation. Greenish-brown or brown thin-bedded sandstones, sometimes glauconitic, are common in these lower beds while grey-green or buff-coloured marls, sometimes mud-cracked and occasionally nodular, are more common in the upper beds. They contain obscure casts of lamellibranchs and occasional phosphatic bone fragments. Some limestones contain algae, ostracod, bryozoa, and shell fragments, otherwise fossils are rare except in the uppermost 3 m. limestones which is shelly, conglomeratic, and with rounded phosphatic pebbles and in which the bedding planes are often crowded with lamellibranchs such as *Pteria* and *Avicula*. The lithology of this formation is similar to that of the beds below rather to that of those above: it is therefore included in the Elphinstone Group.

Comparable Successions

For the most part the Permian and Triassic strata of the Middle East outcrop in deeply eroded anticlines in the foreland of the Zagros and Taurus Mountains. The nearest of such outcrops to those of the Oman Peninsula is in the Zagros Foreland of south-east Laristan, Iran, where at Kūh Gahkun and Kūh Furgun, about 30 miles north of Bandar Abbas, a Permo-Trias succession of *c.* 1,950 m. is exposed (Douglas, 1936, 1950; Geological Staff, British Petroleum, 1956). The upper *c.* 180 m. of this succession (Text-fig. 1) is equated to the upper part (Asfal to Shuba Formations) of the Elphinstone Group. It consists of a lower group, *c.* 60 m., of black and yellow limestones, possibly with *Dicerocardium*, a middle group, *c.* 60 m., of khaki shales with *Lopha parasitica* (Krumbeck) (= *L. blanfordi* Lees), *Mytilus*, *Pteria*, and *Pholadomya*, and an upper group, *c.* 60 m., of red and orange siliceous and dolomitic limestones. Below these there are *c.* 1,200 m. of laminated thin bedded buff-coloured limestones, sometimes oolitic or dolomitic. These represent the Hagil to Milaha Formations of the Hagab area: Douglas (1950) expressed the view that their lower part might be of Permian age. The next 575 m. are considered to be of Permian age. They consist of an upper 515 m. of grey thin-bedded laminated limestones, the lower half of which contain the corals *Iranophyllum*, *Waagenophyllum*, and *Wentzelella*, and at the top, the foraminifera *Schwagerina* aff. *vulgaris* (Schellwien) and *Parafusulina*. They are equated with the Bih Dolomites. Below them there are 60 m. of flaggy limestones with a *Marginifera* fauna of Sakmarian age (Douglas, 1950; Hudson and Sudbury, 1959). These have not as yet been recorded from the Oman Peninsula. The succession and thicknesses at Gahkun thus confirm those of the Jebel Hagab area. Other sections further north show similar successions.

In the foreland of the Oman Mountains south of the Peninsula there are no exposures of Permian or Trias until Haushi (21° 02′ 3″: 57° 36′ 2″) where Jurassic limestones rest unconformably on the Lusaba Limestone which contains the *Marginifera* fauna of Artinskian-Sakmarian age (Hudson and Sudbury, 1959). This elimination of the Permian and Trias continues southwards, for in Dhofar and the Hadramaut (Arabo–Somali Massif) the Jurassic rests on Lower Palaeozoic or Pre-Cambrian. The change is shown on borings in the foreland. The nearest of these to the Peninsula is that at Fahud (Text-fig. 1). There 1,004 m. of Permo-Trias was encountered below the depth of 1,941 m. The base of this succession is firmly dated by the occurrence of the *Marginifera* fauna in thin marly limestones at a depth of 2,906 m. (Hudson and Sudbury, 1959). At the top of the succession, below Jurassic strata, there are 10 m. of calcareous siltstone underlain by 24 m. of grey siltstones and green-grey and red shale



TEXT-FIG. 1.—Comparative sections of Permo-Trias of Zagros and Oman Forelands.

and mudstone with 7 m. of limestone towards their base. These are the only clastic rocks of importance in 2,095 m. of Permian to Lower Cretaceous limestones. They are here named the Fahud Formation. Lithologically they are similar to the Sumra to Shuba Formations and occupy the same stratigraphical position: they are thus equated with them.

About 365 m. below the Fahud Formation there are dolomitic limestones and anhydrite with *Lingula tenuissima* Bronn. These beds are about at the Permian–Triassic junction since, below them, dolomitic limestones contain, as does the Hagil Limestone, a fauna which variously includes *Agathammina*, *Climacammina*, *Cribogererina*, *Geinitzina postcarbonica* Spandel, *Globivalvulina*, *Glomospira*, *Hemigordius*, *Pachyphloia*, and *Padangia*, and is considered to be of Permian age. The Permian is thus of similar thickness to that of the J. Hagab area: the Trias is much thinner, and is considered to be the equivalent of only the lowest part of that exposed in the J. Hagab area and to be unconformable under the Fahud Formation.

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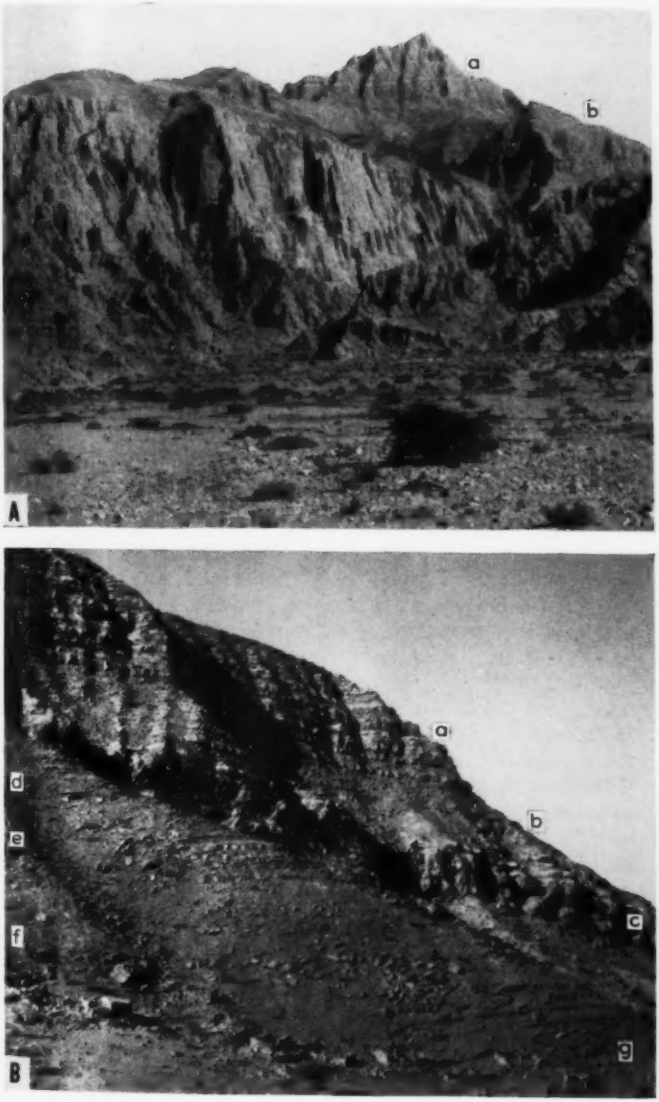
EXPLANATION OF PLATE IX

A. Jebel Hagab (1,500 m.) from Wadi Bih. a, lower part (Lower Jurassic) of Musandam Limestone with "white band"; b, Elphinstone Beds (Noric). Cliff of Ghail Limestone (Trias).

B. Left bank of Wadi Milaha above Hubous shelters. a, lower part of Musandam Limestone; b, Shuba Limestone and Marl; c, Sakhra Limestone; d, *Lovcenipora* Limestone; e, *Dicerocardium* Limestones; f, sandstone marker; g, top of Milaha Formation. b–g, Elphinstone Beds; above d, Sumra Formation; between d–g, Asfal Formation.



TRIAS OF OMAN, ARABIA.

facing p. 308

A New Instrument for Determining Planar Orientation

By F. G. Berry

Abstract

A new instrument for the use of field geologists in orientation studies is described; the method of use is outlined and briefly appraised in comparison with common practice.

I. Introduction

Planes of schistosity, jointing, cleavage, normal, and cross-stratification are usually seen edge-on in exposures, with their surfaces concealed. The problem is to find their true dip or strike. The following methods are some that are commonly used.

The exposing face is excavated to lay bare the planar surface and the direction of maximum dip is found by placing a bubble-level on it. Alternatively, the edge of the structure is cut back until a horizontal (strike) direction is apparent—again, using a bubble-level, but in this case in contact with the edge.

The exposing face may be cut into to reveal the structure in two directions, so that its orientation is apparent. A flat plate having a bubble-level attached, is then thrust into the rock, following the plane of the structure and the strike or direction of maximum dip found from the bubble-level (see Pyror, 1958).

As a variant of the two-dip problem, the direction of true dip is found graphically. The compass bearings and inclinations of two apparent dips are plotted on the Wulff net, as described by Phillips (1954).

None of the foregoing methods are very satisfactory. Preliminary excavation is extremely laborious and time-consuming, especially when, as is very often the case, the number of units to be measured is several hundreds. Excavation, moreover, is often impossible in hard-rock areas. In this case, it would seem that a graphical solution should be applied; judging from a recent discussion (see Fisher, 1958) this may assume an unwarrantable complexity. Indeed, the whole of the literature devoted to this solution suggests that it is more academic than practical in character.

One solution to this difficulty was used by Dawson-Grove (1955, p. 8), involving the alignment of an independent tilt-plate on ball-and-socket joint with the structure and direct measurement of the plate.

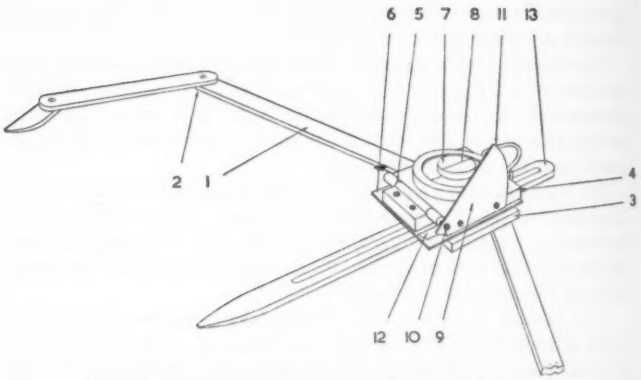
The writer has constructed a new instrument which is claimed to be expeditious. With it, the orientation of *any* planar surface can be determined quickly with reference to the magnetic north and the horizontal. The instrument was primarily intended to resolve the orientation of concealed structures seen edge-on, but it may be used,

without modification, to find the orientation of exposed planar surfaces.

The writer acknowledges many useful suggestions and criticisms in preparing this paper, made by Dr. C. Tozer.

II. Design of Instrument

The basis of the instrument consists of three metal legs (Text-fig. 1—I), attached by pivot-screws to a flat metal plate (3). The two outer ones are provided with knee joints (2) and the centre one can be moved backwards or forwards. A compass (4) is fixed by means of a hinge (5) to a second flat plate (6). This in turn, is fixed by means of a single



Text-fig. 1.—The new instrument (part of one leg omitted).

screw to the plate (3) so that it can be rotated to any direction. A circular bubble-level (7) is fixed to the glass of the compass and is of such a diameter that a gap is left round the circumference through which the card and needle can be seen. A fine white line (8) is painted diametrically across the glass of the bubble-level and continued across the glass of the compass, precisely at right-angles to the hinge.

The clinometer (9) is constructed from a sector cut from a plastic protractor. This is fixed by two screws to the sides of the compass, the centre-point being accurately aligned with the pin of the hinge by which the compass is attached. This point is subsequently drilled out to take a small screw and nut (10) which forms a pivot for the clinometer cursor (11) cut from thin brass strip and drilled for the pivot screw. The lower end (12) is bent round so that it just touches the plate when the upper end (11) reads zero degrees. The pivot-screw nut is adjusted so that a small amount of friction is obtained between the cursor and clinometer.

III. Use of Instrument

The legs are adjusted to the shape of the outcrop and their tips applied to it, the end of the central leg (13) forming a convenient handle. In the event of the exposing face being perfectly flat, a piece must first be knocked out with a hammer so that the tips, when applied, are not aligned.

Now the three legs occupy a common plane, since they all lie flat against the under surface of the plate (3) and when their tips are simultaneously in contact with the edge of the planar surface whose orientation is to be determined, it follows that the plate (3) must lie in a plane parallel to it. This part thus forms a convenient extension of the concealed surface upon which the direction and amount of maximum dip may easily be determined.

The direction of maximum dip is obtained by observing the position of the bubble in the level. First the compass is rotated until the white line on the level intersects the bubble. The pin of the hinge of the compass is now parallel to the strike of the plane whose inclination is being measured; while the white line gives the azimuth (bearing) of the direction of maximum dip.

In order to measure the inclination to the horizontal the compass is now raised on its hinge through a vertical arc until the bubble becomes central. In raising the compass the clinometer has been rotated around the cursor, which is prevented from moving by the lower end (12) touching the plate (6). After noting the bearing, the compass is lowered again and the cursor, which is held against the clinometer by friction, indicates the angle through which the compass has moved—i.e., maximum dip.

It is essential, of course, that the compass should not be raised so far that the bubble goes over the mid-point of the level.

To determine the orientation of exposed surfaces the instrument is laid upon the surface and the same procedure followed.

IV. Discussion

The instrument uses a direct contact method and obviates the need for the two or three instruments which are normally carried and used separately. Little or no excavation of the exposing face is necessary before it is used; a useful reading can be obtained when the three points of location depart from alignment by as little as one inch.

The distance between the points of the legs is usually such that small-scale undulations or variations in dip are smoothed. It is also a simple matter to find the orientation of strongly ripple-marked surfaces by adjusting the tips to touch either troughs or crests.

The instrument can be used in hard-rock areas, when it is desirable to furnish the tips of the legs with rubber points to eliminate slip.

When being used to determine the orientation of exposed planar surfaces, the instrument performs the same function as the device described by Berthois (1951).

A certain amount of practise is necessary in the field before the operator becomes expert ; once the necessary familiarity is achieved, the whole process becomes extremely simple and rapid.

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5 CASTLE CRESCENT,
READING.

The Laig Gorge Beds, Isle of Eigg

By J. D. Hudson

(With an appendix on the foraminifera by C. G. Adams.)

Abstract

Some rocks exposed near Laig Farm, Isle of Eigg, have previously been referred to the Upper Oxfordian. In this paper their age is shown by foraminifera to be Upper Cretaceous, their petrology described, and their stratigraphical significance discussed. Evidence is presented that the supposed unconformity below the Lower Corallian of North-West Scotland does not exist.

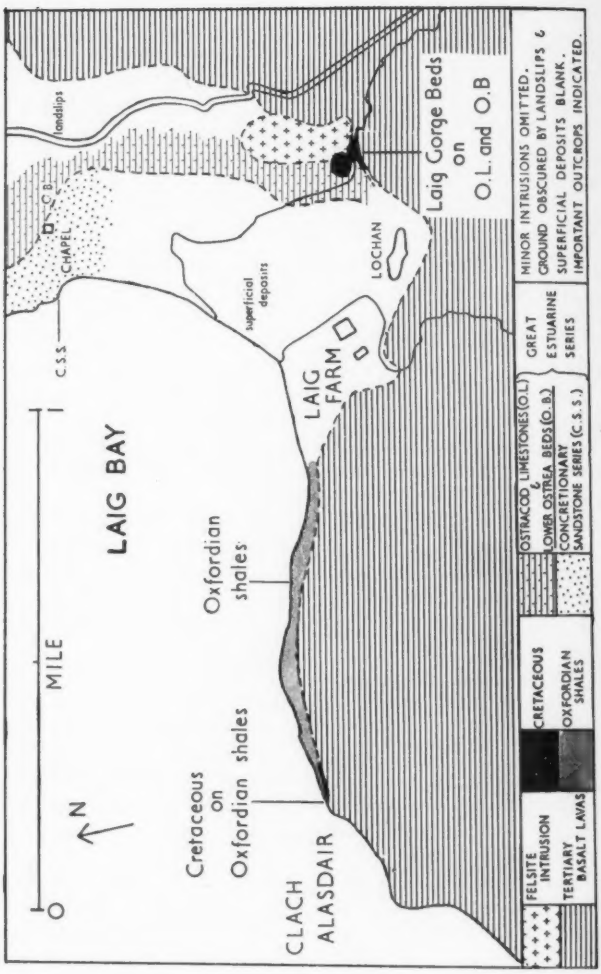
Introduction and Previous Work

In the Isle of Eigg, to the south of Skye in the Inner Hebrides, sedimentary rocks of Jurassic and Upper Cretaceous age are overlain by Tertiary basalts. The basalts form the higher ground in the north of the island, and almost the whole of the southern part, owing to a gentle southerly dip. The coastal lowland in the north is underlain mostly by the Great Estuarine Series, of Bathonian (Middle Jurassic) age. Mesozoic rocks younger than this are exposed in two localities only, in the south-west of the Mesozoic tract. To the north and east they are overstepped by the basalts, which come to rest on the Great Estuarine Series.

At the first locality, a small gorge near Laig Farm, the beds which form the subject of this paper rest on the Great Estuarine Series and are overlain by basalt. At the second, on the south side of Laig Bay, shales of Oxfordian age are exposed, and near the headland of Clach Alasdair are overlain by a thin development of Upper Cretaceous. Resting on this is Tertiary tuff and basalt (see Text-fig. 1).

In the Small Isles Memoir (1908, pp. 26–7) Barrow describes the Laig Gorge section as showing 8 feet of limestone, underlain by 12 feet of calcareous sandstone resting on the Estuarine shales. A brief lithological description of the rocks is given, and the following fossils are recorded from the base of the calcareous sandstone: *Terebratula* sp., *Ostrea* sp., *Cucullea* sp., *Astarte* sp., Lamellibranch, Gastropod, *Belemnites* sp., *Ichthyosaurus*, Reptilian tooth, fragment of bone. This assemblage is not diagnostic.

The section on the south side of Laig Bay is also described in the Memoir, and a considerable list of fossils from the shales is given, including *Cardioceras cordatum*, *C. excavatum*, and *Aspidoceras perarmatum*. These beds were later correlated by Pringle (Lee and Pringle, 1932) with the Lower Calcareous Grit of the Corallian (*cordatum* zone); Arkell (1956, p. 23) mentions them under the *plicatilis* zone. They are certainly late Lower or early Upper Oxfordian in the modern sense. (Some confusion is possible since the authors of



TEXT-FIG. 1.—Geological sketch-map of Laig Bay, Isle of Eigg.

the Memoir use Oxfordian to mean equivalent to the English Oxford Clay). The correlation of the Upper Cretaceous is lithological.

The present paper is mainly concerned with the Laig Gorge section. Barrow appears to have assumed without argument that the limestone and sandstone there—the Laig Gorge Beds, as I propose to call them—were older than the Oxfordian shales. He correlated them (1908, p. 30) with the basal bed of the " Oxford Clay " of Strathaird in Skye, which was then believed to be of Upper Oxfordian age (this is discussed later in the paper), and also compared them lithologically with the Brora Roof Bed (Lower Callovian) of East Sutherland. It should be noted, however, that the Laig Gorge Beds are not seen in contact with the Oxfordian shales—there are no relevant exposures between Laig Gorge and the south side of Laig Bay. All that can be deduced from their field relations is that they are younger than the local top of the Great Estuarine Series (i.e. some part of the Bathonian) and older than the Tertiary basalts. However, Pringle (Lee and Pringle, 1932, p. 210) refers to the limestone as being " overlain by " the shales; he accepts the Lower Corallian (= Upper Oxfordian) age of the Laig Gorge Beds and uses it as part of the evidence for his sub-Lower Corallian unconformity. The status of this unconformity will be considered later. Evidence presented in the appendix to this paper shows that the Laig Gorge Beds are in fact Upper Cretaceous.

2. The Laig Gorge Beds

The section is exposed in and around a small gorge E.N.E. of Laig Farm, grid reference 473 874. The beds are flat except where disturbed by Tertiary intrusions—basalt dykes and a small " knob " of felsite (see sketch-map, fig. 1). The succession is given in Table 1. There are no other exposures.

Table 1.—Laig Gorge Beds

	ft.	*in.*
(Basalt)		
Laig Gorge Limestone. Very fine-grained at the top, becoming somewhat sandy downwards. A limestone-pebble bed 1 foot above the base	7	6
Main Nodule Bed. Fine-grained calcareous nodules in coarser calcareous sandstone, forming a transition between the sandstone and the limestone . . .	0	6
Laig Gorge Sandstone. Coarse calcareous sandstone. At the base a conspicuous Conglomerate with numerous phosphatic pebbles, also vein quartz, etc.	8	9
(Ostracod Limestones of Great Estuarine Series, here mostly shales.)		

(*a*) *Basal Conglomerate*

This consists of pebbles, up to 2 inches long, in a matrix of coarse

calcareous sandstone. Pebbles of vein quartz and flakes of shale from the immediately underlying beds are common, and quartzite pebbles occur. But most of the pebbles are phosphatic, many being also oolitic. There is no doubt that these are pebbles, and not nodules formed *in situ*, nor a band at the base of the rock. The Memoir description is obscure on this point.

(i) *Petrology of the Oolitic Pebbles.*—Thin sections of these pebbles show ooliths of chamosite, and corroded grains of quartz, quartzite, vein quartz, microcline, and micro-perthite, in a matrix of isotropic collophane. The fine matrix seems also to include a clay mineral of low birefringence (kaolinite ?). The ooliths are about 0·5 mm. in diameter, and show good concentric structure and an extinction cross

TABLE 2.—PARTIAL CHEMICAL ANALYSES—PHOSPHATIC PEBBLES

%	*I.*	*II.*	*III.*	*IV.*
P_2O_5 .	29	14	26	26
CaO .	41	23	33	42
FeO .	1·2	2·2	2·9	0·4

I. Non-oolitic phosphatic pebble, Laig Gorge Beds, basal conglomerate.
II. Sandy chamosite-oolite phosphatic pebble, Laig Gorge Beds, basal conglomerate.
III. Chamosite-oolite phosphatic pebble, Dogger, Blea Wyke Point, Yorkshire.
IV. Phosphatic pebble, Cambridge greensand, Barrington, Cambs.

CaO determined soluble in hot dilute HCl, FeO soluble in hot dilute H_2SO_4, P_2O_5 in hot concentrated HNO_3. CaO and FeO by titration, P_2O_5 colorimetrically.

between crossed nicols. The chamosite is pale greenish-yellow, slightly pleochroic with *Y* or *Z* more green-brown, *X* yellower. The birefringence is about 0·10, rather high for chamosite. The mineral is nearly uniaxial, negative. The nuclei of the ooliths are quartz and microcline grains, flakes of chamosite, and broken ooliths. Some of the ooliths are partly or wholly replaced by calcite. The pebbles much resemble those in the Yorkshire Dogger described by Rastall and Hemingway (1939, p. 369, and 1940, p. 271).

Partial chemical analyses of two of the pebbles, with pebbles from the Dogger and the Cambridge greensand for comparison, are given in Table 2. The analyses were carried out by the rapid methods described by Archer, Flint, and Jordan (1958), and Shapiro and Brannock (1956). They are good approximations, but not as accurate as classical analyses. All the pebbles contain some free calcite as well as carbonate combined in collophane, which has a variable composition, and have an insoluble residue of clay. In addition, the Laig Gorge pebbles contain a little pyrite.

(ii) *Sandstone Matrix.*—Thin sections of the coarse sandstone forming the matrix between the pebbles show detrital grains in all

respects similar to those in the pebbles. There are also common grains of bluish green glauconite. These appear to be graded with the sand, and are presumably detrital. Glauconite has not been seen inside the pebbles, nor chamosite outside them. Between the grains is a fine-grained calcareous matrix with a few foraminifera, similar to the Laig Gorge Limestone.

(iii) *Order of Formation.*—This was probably (1) formation of chamosite, (2) phosphatization, (3) sedimentation of present rock, with incorporation of pebbles and arrival of glauconite and foraminifera. Probably no large time interval separated these events, since the grains within the pebbles are so similar to those outside.

(iv) *Fossils.*—All the fossils recorded by the Survey, except the belemnites and bone fragments, were from the phosphatic pebbles. They have been re-examined, and are scarcely generically identifiable.

TABLE 3.—HEAVY MINERALS, LAIG GORGE SANDSTONE

Mineral.	*Percentage.*
Zircon	49
Garnet	18
Rutile	15
Staurolite	9
Tourmaline	6
Kyanite	3

330 grains counted. Opaque grains, 45 per cent of original total, not included.

A more important find was that of an ammonite, certainly derived and apparently phosphatized, made by Mr. D. M. Wright in the company of the author. It was in the main conglomerate, not in a pebble. This ammonite has been identified by Dr. M. K. Howarth (*in litt.*) as " definitely a Cardioceratinid, in fact there is little doubt that it belongs to the sub-genus *Cardioceras* (*Scarburgiceras*); the species is not determinable. This makes the age of the fossil Lower Oxfordian ". The significance of this will be discussed later.

(*b*) *Laig Gorge Sandstone*

Above the basal conglomerate this is a fairly coarse calcareous sandstone, average grain size 0·1–0·2 mm., becoming somewhat finer towards the top. The sorting is poor and stringers of small pebbles occur. The grains, which are often corroded, include much strained quartz, quartzite, often metamorphic with preferred orientation of the grains, microcline, orthoclase, sodic plagioclase, chert, and shale chips. The heavy minerals are considered later (p. 319). The matrix is usually fine-grained calcite mud, probably including some clay, with a few foraminifera. It is sometimes recrystallized to coarser calcite.

(i) *Fossils.*—Apart from the foraminifera, there are occasional,

evidently derived, belemnite fragments, and a few large shell fragments. A cyclostomatous bryozoan has been identified by Dr. G. Larwood as *Ceriopora* sp.

(*c*) *Main Nodule Bed*

The nodules are like the sandier basal part of the limestone, the matrix like the top of the sandstone. The nodules weather out on the surface in very irregular shapes—this level is the main parting in the succession and forms the lip of a small waterfall. The irregular shapes suggest that the nodules were not pebbles. There is a great concentration of styolites along the boundaries of each nodule, and removal of material along these must have helped to produce the nodules.

(*d*) *Laig Gorge Limestone*

This grades from somewhat sandy at the base to very fine-grained and very pure at the top. It is pale grey, weathering white, and is hard and brittle. Stylolites, lined with what seems to be phosphatic material are common throughout. One foot above the base is a 3-inch bed of pebbles or nodules of purer limestone in sandier limestone. The nodules, unlike those of the main nodule bed, weather in the same way as their matrix, and are rounded or oval in outline. Although their margins are now stylolitized, they may represent original pebbles. There are a few nodules of pyrite.

Sections of the main limestone show prismatic shell chips, echinoderm fragments, " spheres " like those in the chalk, foraminifera, and ostracods in a matrix of very fine-grained calcite. The rock is a very fine-grained shell fragment limestone. There are a few very small quartz grains. The foraminifera have been studied by Dr. C. G. Adams, whose report is appended, and they demonstrate the Upper Cretaceous age of the limestone. Macrofossils are very rare. Only unidentifiable shell fragments and a derived bone fragment have been found.

3. Deposition and Derivation of the Laig Gorge Beds

The Laig Gorge Beds, which are Upper Cretaceous, rest on the Ostracod Limestones of the Great Estuarine Series. The Glauconitic Sandstone of Clach Alasdair, about a mile away, which is probably Cenomanian, rests on Oxfordian shales (see Text-fig. 1 and Table 4). This is of course part of the well known unconformity below the Cretaceous of North-West Scotland, first described by Judd. There must be a pre-Upper Cretaceous fold or fault between Clach Alasdair and Laig Gorge, with dip or downthrow to the west. A fault is perhaps more likely. It could be of the same age as the Camasunary fault in Skye (Wedd, 1910), though its downthrow would be in the opposite direction and much smaller. Comparison with South Skye (Table 4)

suggests differential erosion of at least 250 feet of sediment on the Laig Gorge side. That erosion of Lower Oxfordian beds was proceeding during the deposition of the Laig Gorge Beds is proved by the ammonite in the basal conglomerate, referred to earlier. It is interesting to note that phosphatized chamosite-oolite pebbles, like those in the Laig Gorge Beds, occur in a rather similar situation in the Dogger of Yorkshire, with Upper Lias clays being eroded. Rastall and Hemingway (1940, p. 273) suggest that the formation of chamosite oolite there may be penecontemporaneous with its erosion and phosphatization. During the deposition of the Laig Gorge Beds the supply of detrital

TABLE 4.—STRATIGRAPHY OF THE JURASSIC-CRETACEOUS BOUNDARY, EIGG AND SOUTH SKYE. (THICKNESSES IN FEET.)

	LAIG GORGE, EIGG	CLACH ALASDAIR, EIGG	STRATHAIRD, SKYE
UPPER CRETACEOUS	LAIG GORGE BEDS (this paper) 16	(higher Cretaceous beds) GLAUCONITIC SST. 1+	(higher Cretaceous beds) SANDY LST.* 5+
OXFORDIAN	———	SHALES WITH CARDIOCERAS base not seen	DARK SHALY SST. WITH CARDIOCERAS 250 SHALES, MARIAE ZONE NEAR TOP 70
CALLOVIAN	———		?——?— SANDSTONES 30
BATHONIAN (GREAT ESTUARINE SERIES)	OSTRACOD LST. 20 LR. OSTREA BEDS 25 base not seen in Laig Gorge		?——?— MOTTLED CLAY 60 OSTRACOD LST. 80 LR. OSTREA BEDS 20 lower beds of Estuarine series

* Probably Cenomanian, but correlation lithological (J. M. Hancock, personal communication).

sediment steadily diminished, though such as did arrive was coarse grained, until virtually pure calcareous muds were laid down, and now form the limestone. That the Laig Gorge Beds are very different from the nearby development at Clach Alasdair is not surprising, as the Hebridean Cretaceous is known to be extremely variable.

(i) *Derivation.*—Heavy minerals were separated from a sample from the middle of the Laig Gorge Sandstone (Table 3). The zircon includes pink zircon, and is mostly rounded. The garnet is fresh and very angular, mainly colourless but including large flesh red and pale pink grains. The kyanite is very ragged and corroded.

The assemblage resembles those found by the author in the Great Estuarine Series. The abundance of fresh angular garnet and staurolite, and the presence of kyanite, suggest derivation from metamorphic rocks. The rounded zircon and the rutile indicate that sedimentary

rocks too formed part of the source area. The Scottish mainland is the only obvious source for this assemblage.

4. Discussion of Jurassic Stratigraphy

It has been mentioned that Pringle (Lee and Pringle, 1932, pp. 162 and 201) used the section in Laig Gorge as part of the evidence for his sub-Lower Corallian unconformity. This paper shows that the rocks in Eigg do not, in fact, give any evidence on the relation between the Oxfordian (Lower Corallian) clays and the underlying strata.

Recent work in Skye has shown that there is no evidence for this unconformity there either. Pringle claimed that the Great Estuarine Series was followed by marine Cornbrash (in Raasay, where no higher strata are exposed), Kellaways and Lower Oxford Clay, these now surviving only in scattered fragments, and that after uplift and erosion marine Lower Corallian was deposited over the whole area. The present state of the evidence is reviewed below.

(*a*) *Trotternish, North Skye*

Anderson (summaries 1948a and b, see also MacGregor, 1934) has demonstrated a complete succession of Oxford Clay in Staffin Bay, beginning with the *jason* zone which rests on the Great Estuarine Series, and continuing into the Upper Oxfordian (or Corallian) and Lower Kimmeridgian. The Belemnite Sands at the top of the Great Estuarine Series are probably Callovian. A fragment of an ammonite is not inconsistent with this age (Dr. F. W. Anderson, personal communication). There is no reason to suppose a large stratigraphical break anywhere in this succession.

(*b*) *Strathaird, South Skye*

Wedd (1910), quoted by Pringle, claimed that the Great Estuarine Series was overlain directly, or nearly so, by Lower Corallian clays and sands with *Cardioceras cordatum*. A Kellaways (Lower Callovian) fauna was found in loose blocks on the beach—the blocks were supposed to have fallen from a thin and discontinuous deposit below the Lower Corallian. However, Dr. F. W. Anderson and I, independently, have found the Kellaways beds *in situ*—they are coarse sandstones with numerous belemnites resting sharply on the Great Estuarine Series (Mottled Clays) and extending upwards for about 30 feet. They may be equivalent to the Belemnite Sands at the top of the Great Estuarine Series in Trotternish. Above them come poorly exposed black shales, then thick shaly sandstones with abundant *Cardioceras* (Table 4). The lowest ammonite I have been able to find was near the top of the black shales, 15 feet below the base of the shaly sandstones. It has been identified by Dr. M. K. Howarth as

Cardioceras (*Scarburgiceras*) *praecordatum* R. Douvillé of the *mariae* zone of the Lower Oxfordian. It is quite probable that still lower Oxfordian and Upper Callovian zones are represented in the shales, and that the succession is complete.

(*c*) *Mull*

Buckman's records of "*ornatus* beds" ammonites of the Lower Oxford Clay were shown by Arkell (1933, p. 371) to refer to Kimmeridgian material and are therefore not relevant.

A more accurate sub-division of the Callovian–Oxfordian beds of the Hebrides awaits further work on the ammonites, but it can confidently be stated that there is no evidence for any major break in the succession.

5. Conclusions

(1) The Laig Gorge Beds are Upper Cretaceous (see Appendix).

(2) They rest non-sequentially on the Great Estuarine Series, with a basal conglomerate including phosphatized chamosite-oolite pebbles, followed by sandstone and fine-grained limestone with "spheres" and foraminifera.

(3) During the deposition of the Laig Gorge Beds, Oxford Clay was being eroded nearby, but the main source of detrital sediment was the Scottish mainland.

(4) The removal of the Laig Gorge Beds from the Oxfordian removes an important part of the evidence for the supposed pre-"Lower Corallian" unconformity of this area, and the rest of the evidence for it is not considered to be convincing.

6. Acknowledgments

I wish to thank particularly Dr. C. G. Adams for contributing the appendix to this paper on the foraminifera. I should like also to thank Dr. M. K. Howarth for identifying the ammonites, and Drs. F. W. Anderson, J. M. Hancock, and M. Black for useful discussions and information. Dr. Hancock and Dr. W. W. Black read the draft of the paper and made helpful suggestions. Part of the work was carried out during the tenure of a D.S.I.R. grant.

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A Note on the Age of the Laig Gorge Beds, Eigg

By C. G. ADAMS

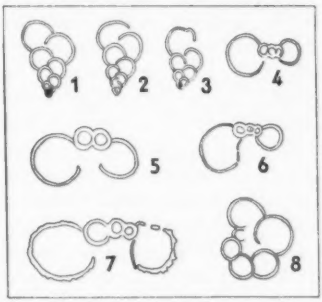
THE writer was asked to examine samples of the Laig Gorge Beds to try to determine from the micro-fauna whether or not the rock was of Jurassic age, as previously thought, or younger. Seven rock samples taken from various levels within the limestone and underlying sandstone were sectioned and examined, namely:—

E 16 and E 106/1 : both 6 in. below the top of the limestone (i.e., from the base of the basalt).
E 17 : 2 ft. above the main nodule bed.
E 101/1 : nodule from the upper nodule bed, 1 ft. above main nodule bed.
E 102/1 : matrix of upper nodule bed.
E 104/1 : sandy limestone, 3 in. above the main nodule bed.
E 21/3 : phosphatic pebble in calcareous sandstone, basal conglomerate of Laig Gorge Beds.
Total number of sections, 18.

A foraminiferal fauna occurs throughout the limestone, but in the lowest sample (E 21/3) it is confined to the calcareous matrix in which angular sand grains and phosphatic pebbles are embedded. The nodules in the upper nodule bed differ from the sandy matrix in that they are completely calcareous. The upper, non-sandy part of the limestone consists mainly of chalk spheres with a scattering of fragmented shell debris and foraminifera. The lower part consists very largely of angular or sub-angular quartz grains, set in a calcareous matrix which is similar in appearance to the pure limestone described above.

As the rock is too hard and dense for the fauna to be extracted, determinations have to be based solely on random thin sections. This is always an unsatisfactory procedure, especially when smaller foraminifera are concerned, since many characters of taxonomic importance e.g., shape and position of apertures and accessory structures, cannot be observed. For this reason it is not always possible to give specific determinations or even, in some instances, to be sure of the genus.

Of the small number of foraminiferal species occurring in the limestone only two are of known stratigraphical importance. These are *Heterohelix cf. globulosa* (Ehrenberg) (Text-fig. 2, 1–3) and ? *Praeglobotruncana* (*Hedbergella*) sp. (Text-fig. 2, 4–8). The former is represented



TEXT-FIG. 2.—Foraminifera from the Laig Gorge Limestone.

1–3.—*Heterohelix cf. globulosa* (Ehrenberg) 1, × 83 (E 106/1); 2, × 83 (E 17/2); 3, × 77 (E 102/1).

4–8.—? *Praeglobotruncana* (*Hedbergella*) sp. 4, × 77 (E 102/1). A biumbilicate specimen resembling *Planomalina*.

5, × 49 (E 16/2) Specimen with an unusually elevated upper surface.

6 and 7 both × 82 (E 16/3 and 102/1) Specimens with relatively flat upper surfaces. In 6, the chamber walls are externally roughened and irregular in places.

8, × 49 (E 16/2). One of the larger specimens cut horizontally.

In no instance was the wall structure visible.

by very small individuals, none of which has been observed to exceed 0·18 mm. in length or 0·14 mm. in breadth. The maximum number of chambers counted was nine, usually not more than five to seven being visible, although it is not certain that the full length of any specimen was seen. *Heterohelix* probably ranges throughout the Cretaceous (see Pokorny, 1958, p. 355–356), but the only published records of it from Britain are Williams-Mitchell (1948), who recorded it from the Turonian–U. Senonian of England, and McGugan (1957), who reported it from the Senonian of Northern Ireland: it has not yet been recorded from Albian or older strata. It may be noted that McGugan

(op. cit., p. 340) thought that the presence of small individuals of *Heterohelix globulosa* (less than 1 mm. long) indicated a low Senonian or Turonian age. While it is probably true that the average size of *Heterohelix* is greater in the higher parts of the British chalk, it is possible that the size difference could reflect environmental rather than evolutionary changes.

The specimens here referred to ? *Praeglobotruncana* (*Hedbergella*) sp. have their chambers arranged in a low trochoid spire, the upper surface of which may be almost flat or only slightly elevated. Two or three whorls of chambers are present, there beng five or six chambers in the last whorl. In vertical section the chambers are seen to be rounded, the later ones being inflated. As the aperture and its accessory structures could not be observed it is possible that these specimens should be referred to *Ticinella* sp., in which case the age of the rock would be Albian-Turonian. The stratigraphical range of *Praeglobotruncana* (*Hedbergella*) is, on the other hand, believed to be Aptian-Maestrichtian (see Banner and Blow, 1959). Other genera probably represented in the limestone are *Bolivina*, *Textularia*, *Nodosaria* and *Anomalina*, all of which are long-ranging forms and none of which is specifically determinable in these sections. On this evidence the age of the fauna must be considered to be Upper Cretaceous. The fact that the well-known and commonly occurring genera comprising the family Globotruncanidae are missing from the limestone suggests that the rock is not much younger than Cenomanian. However, Williams-Mitchell (op. cit. p. 107) observed that species of *Globotruncana* were rare in the *Belemnitella mucronata* zone of the English Chalk, so the absence of this genus in the Laig Gorge beds may not be significant.

Previous authors (Jones, 1878, and Hill, 1915) have described foraminifera from the late Cretaceous chalks of western Scotland and have recorded the following genera and species :— *Globigerina cretacea*, *Globigerina*, *Textularia*, *Bulimina*, *Dentalina* and *Planorbulina*. This list is instructive in that it omits any reference to genera which could have been mistaken for *Globotruncana*. (The *Globigerina cretacea* of Jones and the *Globigerina* of Hill are almost certainly referable to *Praeglobotruncana* (*Hedbergella*) sp.). Through the kindness of Dr. J. M. Hancock (King's College, London), the writer was able to obtain some specimens of Senonian chalk from various localities in western Scotland and although most of these proved to be too silicified to be of much use, a few were of interest. One, a black, unsilicified limestone from Strathaird (not the basal sandy limestone of table 4, previous paper), South Skye, contained a good micro-fauna. This limestone revealed in thin section abundant chalk spheres and specimens of *Heterohelix* cf. *globulosa*, ?*Praeglobotruncana* (*Hedbergella*) sp., *Globotruncana* sp., as well as some small benthic foraminifera. This fauna is closely

similar to that of the Laig Gorge Limestone and differs from it mainly in the presence of rare *Globotruncana* (only two individuals were seen in three thin sections). In view of this, it might be considered that the absence of higher Cretaceous marker fossils in the Laig Gorge Limestone is fortuitous, and that this deposit should, therefore, be assigned to the Senonian.

The Laig Gorge Limestone contains Upper Cretaceous foraminifera, but is lacking in forms diagnostic of the higher zones. However, comparison with other known late Cretaceous limestones from western Scotland indicates that the absence of these higher marker forms may be accidental.

The writer wishes to thank Drs. H. W. Ball and F. T. Banner for their helpful comments on reading through the manuscript.

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The Form of the Beinn An Dubhaich Granite, Skye

By Basil C. King

Abstract

The form of the Beinn an Dubhaich granite was considered by Harker to be boss-like. Here evidence is put forward to suggest that it may have the form of a sheet emplaced along the Torridonian-Cambrian thrust plane. The alternative hypothesis has the merit of avoiding the serious difficulties appreciated by Harker regarding the mode of emplacement of the granite.

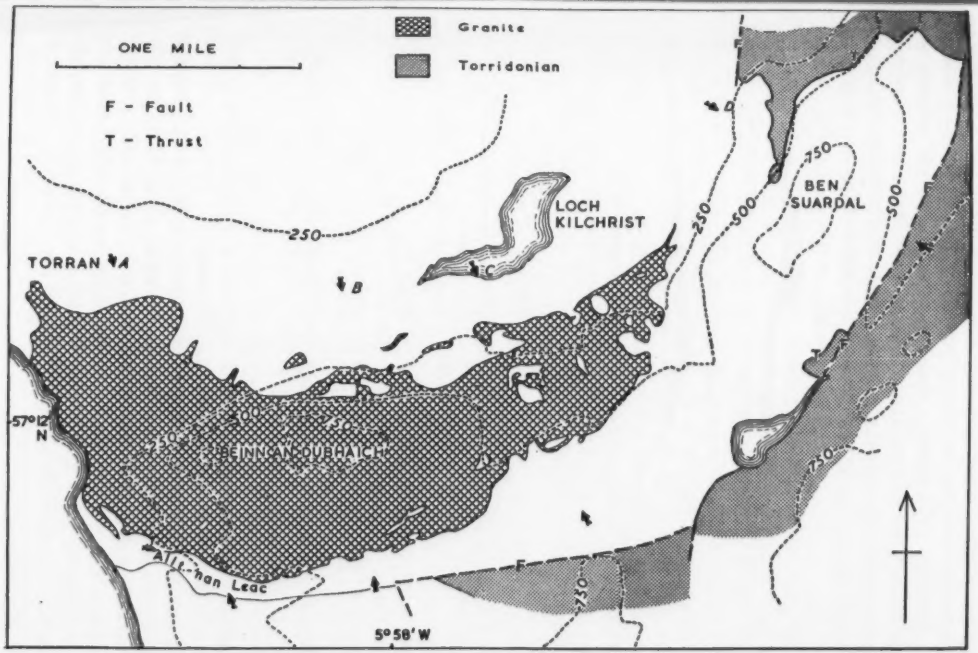
Introduction

The Beinn an Dubhaich granite was described by Harker (1904, 132) as a " typical example of the boss-like mode of occurrence ". This conclusion was based on the observed or inferred character of its contacts with the Cambrian limestone. The boundaries between granite and limestone are in fact very complicated, for within the general area of the granite there occur numerous, often extensive, enclosures of limestone which have the appearance of being undisturbed by the emplacement of the granite. Particularly suggestive of non-disturbance are the pre-granite basic dykes which retain the same habit and alignment both in the surrounding limestone and in the limestone of the enclosures. " This remarkable behaviour presents ", as noted by Harker (op. cit., 135), " a difficult problem in the physics of igneous intrusion " for the " complete absence of limestone xenoliths " is not easily reconciled with a mechanism of stoping, while the unusually low content of the granite in lime is " not to be explained by any theory which involves appreciable incorporation of the country rock in the invading magma ".

The writer has been greatly interested in this problem since first visiting Skye in 1949 and has by now examined most of the exposed contacts of the Beinn an Dubhaich granite. Harker's observations are very generally confirmed, but it is suggested that in spite of the rather numerous observations in detail which apparently indicate a boss-like intrusion with vertical junctions, the granite as a whole has essentially the form of a sheet. It is proposed to discuss the evidence bearing on both of these views more fully, and while it is recognised that no final conclusion can be reached it is hoped that further enquiry may be stimulated. In particular it is thought that the problem may be capable of solution by an appropriate method of geophysical investigation.

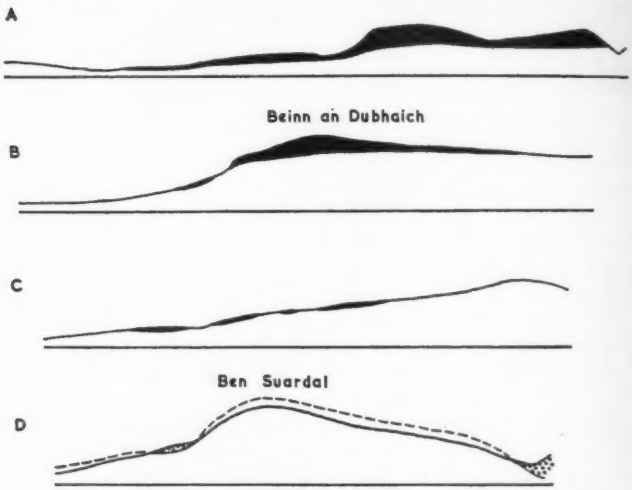
Evidence for a Sheeted Habit

This depends primarily on the three-dimensional picture of the granite mass obtained from a consideration of the relations between the granite-limestone boundaries and the topography. Indeed, the



TEXT-FIG. 1.—Map showing the distribution of granite and Torridonian in the Beinn an Dubhaich–Ben Suardal area. Cambrian limestone occupies most of the area left blank and all of that in the vicinity of the granite and of the Torridonian of Ben Suardal. The boundaries are taken from the Geological Survey Sheet 71.

writer contends that from a mere inspection of the contoured geological map a sheeted habit for the granite is the obvious inference. Irregularities in the margin of the granite and enclosures of limestone within it are confined to those places where the inferred sheet would be thinnest. Conversely, wherever considerations of topography require that the sheet is thick enclosures of limestone are entirely absent. Thus the absence of limestone enclosures from the area above the 600 ft. contour around Beinn an Dubhaich summit is especially



TEXT-FIG. 2.—Sections along lines indicated on map, fig. 1. Solid black—granite; stippled—Torridonian. Vertical and horizontal scales are equal.

significant. Moreover the granite margin and the limits of enclosures closely follow contours at the change in slope.

Even in detail there is often a correlation between the occurrence of enclosures or embayments of limestone and topographic depressions. This is most evident on the map where the enclosures occur in stream courses. Even in the rare exceptions limestone never lies more than a few feet above the level of nearby granite, whereas granite may rise abruptly to tens or even hundreds of feet above adjacent outcrops of limestone.

Form of the Base of the Inferred Sheet

The fact that limestone in some of the enclosures is at a higher level than the granite around part or even all of the circumference shows

that the granite, if a sheet, must have an undulating floor. Most obvious in this respect are certain enclosures to the south-east of Loch Kilchrist where basic dykes and flanking limestone form features standing well above the surrounding granite.

The floor, moreover, must only rarely be horizontal. Thus to the south-east of Loch Kilchrist the southern margin of the granite is up to 300 ft. higher than the northern, but it is important to observe that variations in elevation are systematic and not quite haphazard as might well be the case with a boss-like mass.

Many of the more notable variations in the inclination of the floor appear to conform to a regular pattern. Thus a strongly marked downwarp to the north is to be inferred for a distance of well over a mile along the northern flanks of Beinn an Dubhaich and probably extends along the entire northern margin of the granite. Limestone forms a series of enclosures or embayments at the foot of the main granite scarp, but granite reappears where the slope flattens out again. The floor of the granite thus has the form of a monocline with an axis trending south of west by which the base is lowered by as much as 350 feet. Westwards the depressed portion has a wide extension over low ground to the south of Torran.

To the south of the summit area the granite floor is apparently involved in a series of smaller, but much more acute " folds ", all again trending and plunging gently to the south of west. This pattern is best appreciated when the steep southern flank of the hill is viewed from the south side of the Allt nan Leac. Elongated enclosures of limestone above the valley side appear to be plunging " fold cores " which are exposed again in the side of the valley itself at a lower level (Text-fig. 3).

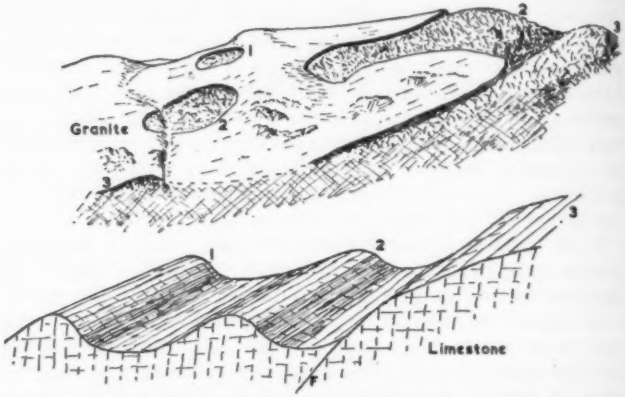
Broadly therefore the floor of the sheet slopes uniformly or else is stepped up toward the south and is also inclined very gently to the south of west, conforming to the direction of plunge of the " folds ". Prior to erosion the " downwarped " area of granite around Torran may have extended towards Kilchrist. Thus the arcuation of the structural pattern of the base of the granite is very slight compared with that shown by the shape of the granite area. It is noteworthy that a similar slight arcuation is seen in the fold axes both of the Cambrian and of the Mesozoics.

Attitude of the Granite-Limestone Contacts

Harker (op. cit., p. 132) states that the junctions between granite and limestone are everywhere vertical. This is a somewhat misleading statement since, although visible junctions are not uncommon, they form only a very small proportion of the entire length of contact. Moreover, in the majority of cases Harker has apparently accepted as

indicative of vertical contacts the observation that the granite stands up as a wall a few feet higher than the adjacent depression occupied by limestone. Exactly similar relations are, however, seen around fenster of Cambrian limestone surrounded by Torridonian sandstone, as on Ben Suardal and Creag Strollamus. In some instances the limestone within the fenster actually stands higher than the nearby Torridonian, implying that exposure of limestone has been favoured by undulations of the thrust plane.

There are, however, a number of places where the actual junction can be seen and its attitude inferred over a distance of several feet.



TEXT-FIG. 3.—Diagrammatic view of the northern slopes of Allt nan Leac looking towards Beinn an Dubhaich. The interpretation of the limestone as forming "anticlinal" cores (numbered 1, 2, and 3) below the granite is illustrated in the lower diagram.

In most cases such visible junctions are indeed vertical, but there are exceptions in which the junction is steeply or even gently inclined. Good examples may be seen on the steep northern slopes of Beinn an Dubhaich and in Allt nan Leac. Wherever inclined junctions have been observed limestone is invariably underlying granite, never the reverse. Indeed, at these two localities the topographic relief is sufficiently great to admit of no other possibility.

At some of the localities showing vertical junctions the contacts are remarkably straight. Examples of such junctions occur at two places around the belt of enclosed limestone to the north of the summit area. Detailed mapping shows that these straight sections of contact form offsets in the more usual sinuous boundaries.

A clear example of a perfectly flat, straight, vertical contact is seen in the old marble quarry three-quarters of a mile south of Kilchrist.

It is suspected that such contacts represent pre-granite faults which determined the positions of the contact (see later p. 333). Harker's mapping, it may be noted, shows none of these abrupt irregularities in the shape of the granite boundary, presumably because his interpretation of the granite as having a boss-like habit made the representation of the contacts as smoothly rounded more plausible.

In some places even where limestone and granite are not actually seen in contact a steep or vertical contact can be inferred from the abrupt termination of basic dykes in the limestone where they abut against the granite (cf. Harker, Fig. 31).

Nature of the Granite and Limestone at Contacts

It is clear that the granite is intrusive towards the adjacent rocks, although evidence of mechanical intrusion is very rarely seen. A few examples of intrusive tongues and dyke-like masses of granite have been noted in the limestone and in one place small dykes and veins of granite penetrate a basic dyke. Harker states that xenoliths of limestone in the granite are never seen, but the writer has observed an inclusion of marble in the marginal granite at a sloping contact on the northern flanks of Beinn an Dubhaich. Around some of the limestone enclosures granite appears to have invaded the limestone more readily than the basic dykes, for these may be directly flanked by granite for distances of a few feet.

The texture of the granite at the contact varies considerably. In some instances it remains virtually unchanged from the normal texture. This is true of the contact in the marble quarry cited above. In other cases the granite passes marginally into a quartz porphyry and sometimes even into a felsite. Since, however, chilled felsitic margins are often very narrow they are only observable where actual contacts are exposed. It is clear nevertheless that the texture of the marginal rock shows great variation over short distances of contact and that the widths of such finer-grained rock, where present, are also variable.

The petrographic and chemical characters of the granite and contact rocks have received considerable attention. Tilley (1949) has shown that metasomatism has occurred in the contact limestone and that the marginal granite is relatively enriched in alkalies, especially potash, while Tuttle and Keith (1954) have found that the alkali feldspars and quartz tend towards high temperature types, normally characteristic of lavas or smaller intrusions.

The limestone is extensively metamorphosed in the vicinity of the granite, but for very variable distances, in places as much as 200 yards from the contact. It is suggested that this is more easily explained if the granite is supposed to be a sheet, which has in some localities only just been removed by erosion.

Structural Inferences

Harker considered that the Beinn an Dubhaich granite was emplaced with a boss-like form within the core of an anticline of Cambrian limestone. The numerous enclosures, since they appear to be undisturbed, he considered to connect in some way with the main mass of limestone. It was indeed difficult to understand on this view how the granite, which must have been emplaced entirely at the expense of limestone, should contain so many undisturbed enclosures and yet be devoid of xenoliths.

These particular difficulties do not arise if the mass is a sheet, for not only is the space problem less, but emplacement could have been achieved by uplift of the overlying formations. Indeed, little or no removal of limestone need be postulated at all.

Assuming a sheeted habit, it is of interest to enquire whether it is possible to infer a pre-existing structural plane by which emplacement was controlled. In this respect the Cambrian-Torridonian thrust plane is the most obvious structure, for it is seen only a mile to the north-east on Ben Suardal and could very well have been represented at around the present erosion surface on Beinn an Dubhaich. On Ben Suardal the thrust-plane is involved in a rather sharp anticline which plunges to the north-north-west and must flatten considerably in the same direction. On its western limb the anticline is accompanied by a much weaker syncline (Text-fig. 2). The base of the Beinn an Dubhaich granite can easily be envisaged as representing a continuation of this same surface to the south-west, a gentle culmination of pitch carrying the surface above the level of the present topography in the intervening ground.

On this view the pattern of folds and undulations which characterise the base of the granite are considered to be folds of the original thrust-plane. They are indeed similar in style and amplitude and, moreover, it is not difficult to infer actual correspondence between individual folds of the thrust-plane and those of the base of the granite. Harker (op. cit., 136) made the significant observation in the nearby area of the Broadford gabbro and Creag Strollamus that granite is typically emplaced along the Cambrian-Torridonian thrust-plane, an observation that the writer has amply confirmed (King, 1952, 384). The Beinn an Dubhaich granite would thus be an even more striking example of the same phenomenon.

Those straight parts of the granite contact which, as has been suggested above, are tectonic, are regarded as representing faults which displaced the thrust-plane in the pre-granite structure. Faults of this kind with small throws are fairly common both on Ben Suardal and Creag Strollamus.

An observation which may be of significance is that basic dykes

penetrate the limestone much more freely than the Torridonian. Two instances are known on Creag Strollamus where dykes terminate abruptly in the limestone against small faults which displace the thrust-plane. It is not impossible that some cases of abrupt terminations of basic dykes against granite reflect similar features in the pre-granite structure.

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A New Species of *Tretaspis* from South Wales

By R. Cave

(PLATE X)

Abstract

Tretaspis moeldenensis sp. nov. from "Bala Limestone" of Carmarthenshire is described. Almost identical forms previously referred to *T. kiaeri* Størmer and *T.* aff. *kiaeri* occur in the *Calymene* Beds of Northern England. The trilobite previously described as *T.* cf. *kiaeri* from the *Phillipsinella parabola* Zone of the Ashgill Series of North Wales is discussed and thought to be another new species.

Family Trinucleidae Hawle and Corda, 1847

Genus *TRETASPIS* McCoy, 1849

Tretaspis moeldenensis sp. nov.

Pl. X, figs. 1–7.

Holotype.—External mould of a cephalon. Sedgwick Museum No. A50668.

Locality.—Vertical bank 4 yards to the rear of Moelden Cottage, 1,730 yards south-south-west of St. Clears Church, Carmarthenshire. Map reference 22758, 21424.

Horizon.—"Bala Limestone," Carmarthenshire.

The bed consists of a grey decalcified mudstone in contact with *Dicranograptus* Shale. The contact seen in the present exposure leaves room for an interpretation other than simple superposition of "Bala Limestone" on *Dicranograptus* Shale. However, the six-inch Geological Survey map indicates the bed to extend laterally into the road section near Mylet. There it is sandy and can be seen to pass downwards to black *Dicranograptus* Shale containing *Dicellograptus morrisi* Hopkinson (Strahan and others, 1909, pp. 51–2 and 56); and other graptolites common to the Nod Glas in Montgomeryshire, a horizon investigated by the writer and shown to belong to the Onnian Stage.

The age of the Moelden deposit might therefore be Pusgillian.

Fragments from the material so far collected indicate the following to be present with *T. moeldenensis*:—

? *Dalmanitina* sp.

Flexicalymene sp. Large cranidium with broad flat gently upturned brim.

Paracybeloides cf. *loveni* (Linnarsson).

Platilichas cf. *laxatus* (McCoy).

Sphaerocoryphe cf. *thompsoni* (Reed).

? *Sampo* sp. Exterior mould of dorsal valve.

Diagnosis.—A large *Tretaspis* with a broad fringe, convex cheek roll, and concave brim. The anterior fringe is declined less steeply than in *T. kiaeri*, making an angle of about 70°–80° from the horizontal.

Indices (following Størmer, 1930, p. 10):—

$$I = 12\text{–}14,\ II = 6,\ III = 7$$

The three outermost pit rows are arranged in radial sulci, similar to *T. kiaeri*.

Description

Cephalon large, semicircular anteriorly with sub-parallel genal angles which are posteriorly prolonged. Maximum width about 23 mm., maximum length about 13·5 mm.

The upper lamella of the fringe forward of the cheeks and axial furrows contains seven concentric rows of pits. In most specimens the innermost row is lost at the extreme anterior and only six rows pass the front of the pseudofrontal lobe. The seventh row can be absent for as much as six radii on either side of the mesial line, but in those specimens where it is complete this innermost row is cramped forward by the encroachment into the fringe of the pseudofrontal lobe.

One imperfect specimen (Geological Survey Collection Nos. TCC 579 and TCC 580) appears to have eight rows of pits lying forward of the axial furrow, but this is probably the effect of a freak superimposition of two different specimens and it is a feature that has not been confirmed in any of the specimens collected personally.

With the exception of the posterior five (approx.) radii, the three outer rows of pits are arranged in strong radial sulci. Within the sulci the two outer pits are disposed towards the distal end, whilst the third pit is set rather apart, at the inner margin. The pits of the two outer concentric rows communicate with the two outermost rows of the lower lamella, and the pits of the third row communicate with the outer row of the inner band of the lower lamella.

In the posterior part of the fringe the sulci are less pronounced and the innermost of the three rows of pits contained at the anterior has here departed to the cheek roll.

The lower lamella shows the same number of rows of pits as the upper. Two rows are concentrically arranged outside the girder and they are complete with the exception of the posterior one, sometimes two, radii. These positions are occupied by single pits (Pl. X, fig. 2). Pits on the inner band of the lower lamella lie in deep radial sulci.

Along the posterior margin of the fringe are found twelve to fourteen pits, the more usual numbers being thirteen and fourteen. These figures include the outermost pit, beyond the girder, and the large pit situated at the corner of the cheek.

The dorsal surface of the cephalon is smooth. The pseudofrontal lobe and each cheek possess a strong central tubercle. A pronounced "antennary" pit occurs in the anterior end of each axial furrow.

Poorly preserved fragments of the pygidium show it to be almost triangular, with the lateral margins curved forwards at the anterior. The maximum width is about four times the length.

Discussion

T. granulata (Wahlenberg) differs in having a greater number of pit rows in the anterior of the fringe and *T. granulata* var. *bucklandi* (Barrande) differs in the irregular arrangement of the pits and in possessing sulci containing only two rows of pits.

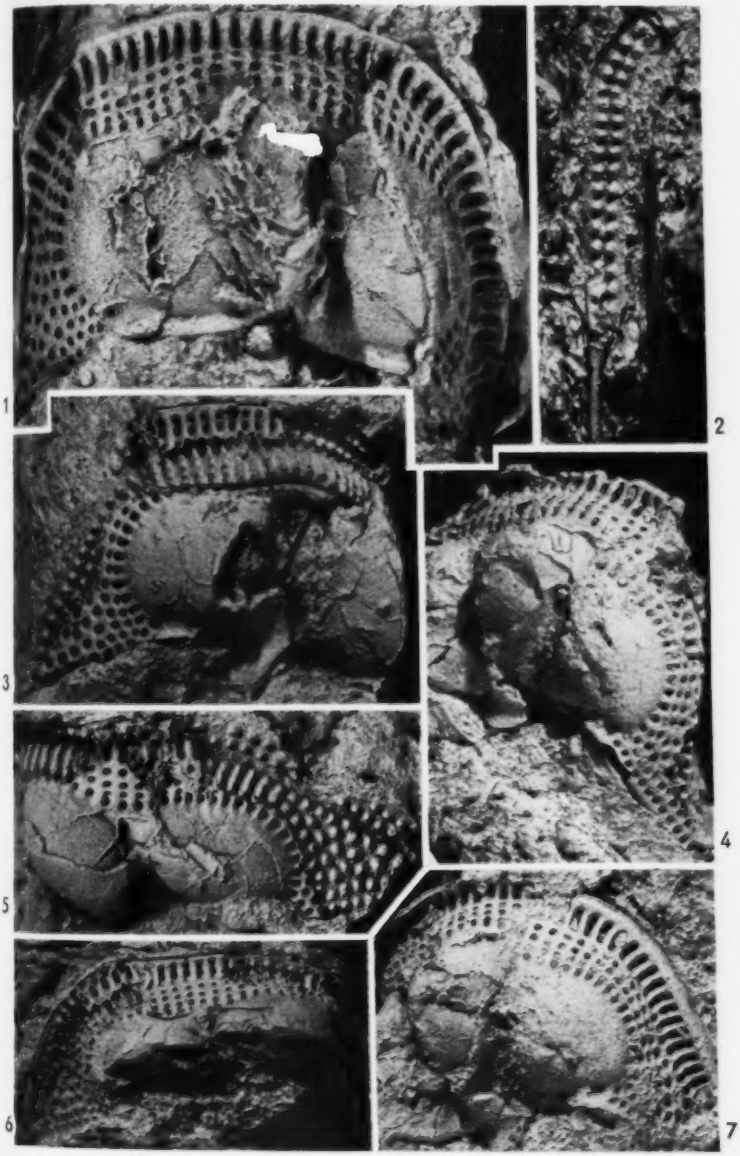
T. kiaeri is the 4bδ zonal species of Norway, having seven to eight rows of pits at the anterior and nine to twelve pits along the posterior margin of the fringe. That found in the Nod Glas (*Onnia gracilis* Zone) of Welshpool, Montgomeryshire, is probably the same. *T. moeldenensis*, however, is almost identical with forms found in other parts of Britain at a horizon just above this.

The form referred to by Lamont (1945, p. 122, pl. 1, figs. 1–3) as *T.* aff. *kiaeri* from the *Calymene* Beds of Sally Beck, Cautley, possesses a slightly higher development of pit rows, having seven at the anterior with thirteen to fourteen pits along the posterior margin, e.g., specimens Nos. A10554a–b and A10553, Sedgwick Museum. Palaeontologically it thus occupies a position very near to *T. moeldenensis*, between it and *T. kiaeri*.

T. kiaeri, listed by King and Williams (1948, p. 210) from the *Calymene* Beds also of Cautley, shows a slightly lower development of pit rows and the innermost or seventh row of pits, at the position of the axial furrow, is sometimes reduced in extent to one or two radii. Very occasionally the seventh row appears to be absent. The posterior margin bears thirteen to fourteen pits, comparable with *T. moeldenensis*, e.g., specimens Nos. A28952 and A28950, Sedgwick Museum. The reference by King and Williams to a reticulate test concerned only the specimen figured by them (1948, pl. xvi, figs. 7A and 7B), and this might be *T. seticornis* (Hisinger).

" *T.* cf. *kiaeri*," showing a further slight reduction in pit rows, has been described from the lower Ashgill rocks of Montgomeryshire (Whittington, 1938, p. 445, pl. xxxviii, figs. 1–3). This is a species smaller than *T. kiaeri* and *T. moeldenensis* and specimens from the *Phillipsinella parabola* Zone at various points in Montgomeryshire possess only six rows of pits forward of the pseudofrontal lobe and axial furrows. Ten to thirteen pits lie along the posterior margin of the fringe. Such characteristics make this a species distinct from *T. kiaeri*.

Grateful acknowledgment is made to Mr. A. G. Brighton for the loan of material and to Professor L. Størmer for his interest and comments.



A NEW *TRETASPIS* FROM S. WALES.

facing p. 336

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EXPLANATION OF PLATE X

Tretaspis moeldenensis sp. nov.

FIG. 1.—Rubber impression of external mould of cephalon, × 4. (Sedgwick Museum A50668c, holotype.)

FIG. 2.—External mould of lower lamella, showing E pits and genal spine, × 4. (S.M. A50669.)

FIG. 3.—Mainly internal mould of cephalon, × 3. (S.M. A50668a.) Counterpart to S.M. A50668b (Fig. 1).

FIG. 4.—Internal mould of cephalon, × 4. (S.M. A50670a.)

FIG. 5.—Part internal mould of cephalon and part external mould of lower lamella, × 3. (S.M. A50671.)

FIG. 6.—Part internal mould of cephalon and part external mould of lower lamella, × 3. (S.M. A50672.)

FIG. 7.—Rubber impression of external mould of cephalon, × 4. (S.M. A50670c.) Counterpart to S.M. A50670b (Fig. 4).

Azimuths of Primary Linear Structures in Folded Strata

By Teoman N. Norman

Abstract

Primary linear structures on plunging folds, when rotated to the horizontal about the strike of the bedding plane, are clearly not in their original " primary " directions. The amount and sign of error has been studied and a method of " plunge correction " is suggested.

I. Introduction

In studies concerning the orientation of primary linear structures, which are now situated on inclined bedding planes, it is usually necessary to " restore " the strata to their original horizontal position. When the inclined bedding planes form a limb of a non-plunging fold, this is achieved simply by rotating the strata about the present strike. In the case of plunging folds, however, this " simple rotation method " will not be satisfactory, since, the azimuth obtained for the linear structure will be in error ; the magnitude of the error depending on the amounts of plunge of the fold axis and dip of the bedding plane.

The presence of this operational error, in cases where the " simple rotation method " has been applied to plunging folds, has been recognized for some time and for detailed work certain geometrical, mechanical (Cloos, 1938), and stereographic methods have been devised. In all of them the basic procedure is first to restore the plunging fold into a non-plunging position, then rotate the bedding plane back to horizontal about its " new " strike, which is parallel to the fold axis. In general, this procedure must be repeated for each measurement which is to be corrected.

This paper describes a method in which the same result as found by the above methods is obtained, with the following additional advantages :—

(*a*) Where a number of correction operations are to be made, this method is far less time consuming than others.

(*b*) The values can be tabulated in such a way that each operation can be checked at every stage.

(*c*) The direct use of the observed field data in calculations, eliminates the intermediate errors due to inaccuracies in drawing, measuring, and plotting, inherent in the previous methods.

(*d*) When the simple rotation method is used, the amount of error

which would occur in various discrete situations can be quickly obtained from Table I, so that the importance of making a correction operation at all can be seen at the outset.

II. The Method

The method consists in first rotating the bedding plane back to horizontal about its present strike in the usual manner (e.g. Wood and Smith, 1958 ; Cummins, 1959). Having thus determined an apparent "original" azimuth for the linear structure, this is corrected to the true original azimuth by the algebraic addition of a factor (ω) which is obtained from Table I by using the amount of plunge of the fold (ϕ) and amount of dip of the bedding plane (α).

Table I.

ω values for discrete amounts of plunge and dip

Amount of dip (α)	Amount of Plunge (φ) 5°	10°	15°	20°	25°	30°	35°	40°	45°	50°
5°	0 00									
10°	0 30	0 00								
15°	0 30	1 00	0 00							
20°	1 00	1 30	1 30	0 00						
25°	1 00	2 00	2 30	2 30	0 00					
30°	1 30	2 30	3 30	4 00	4 00	0 00				
35°	1 30	3 00	4 30	5 30	5 30	5 00	0 00			
40°	2 00	3 30	5 00	6 30	7 30	7 30	6 30	0 00		
45°	2 00	4 00	6 00	7 30	9 00	9 30	9 30	8 30	0 00	
50°	2 30	4 30	7 00	8 30	10 30	12 00	12 30	12 30	10 30	0 00
55°	2 30	5 00	7 30	10 00	12 00	14 00	15 00	15 30	15 00	12 30
60°	3 00	5 30	8 30	11 00	13 00	16 00	17 30	19 00	19 30	18 30
65°	3 00	6 30	9 30	12 30	15 00	18 00	20 00	22 00	23 30	24 00
70°	3 30	7 00	10 30	13 30	17 00	20 00	23 00	25 30	27 30	29 00
75°	4 00	7 30	11 30	15 00	19 00	22 30	25 30	28 30	31 00	34 00
80°	4 00	8 30	12 30	16 30	21 00	24 30	28 30	32 00	35 30	39 00
85°	4 30	9 00	13 30	18 00	23 00	27 00	31 30	36 00	40 00	44 30
90°	5 00	10 00	15 00	20 00	25 00	30 00	35 00	40 00	45 00	50 00
90°	5 00	10 00	15 00	20 00	25 00	30 00	35 00	40 00	45 00	50 00
85°	5 30	11 00	16 30	23 00	27 30	33 00	38 30	44 30	50 00	56 30
80°	6 00	12 00	18 00	24 00	30 00	36 30	42 30	49 30	56 00	63 00
75°	6 30	13 00	19 30	26 30	33 30	40 00	47 30	54 30	63 00	71 00
70°	7 00	14 30	21 30	29 00	36 30	44 30	52 30	61 00	70 00	80 30
65°	8 00	16 00	24 00	32 00	40 30	49 00	58 30	68 00	79 00	91 30
60°	8 30	17 30	26 30	35 30	43 00	54 30	65 30	77 00	90 00	105 30
55°	9 30	19 00	29 00	39 30	50 00	61 30	74 00	87 30	104 00	126 00
50°	10 30	21 30	32 30	44 30	56 30	69 30	84 30	102 00	124 00	180 00
45°	13 00	24 30	37 00	50 30	64 30	80 30	98 30	122 30	180 00	
40°	14 00	28 00	42 30	58 00	75 00	94 30	119 30	180 00		
35°	16 00	32 00	49 30	68 00	89 00	116 00	180 00			
30°	19 00	38 00	59 00	82 00	111 30	180 00				
25°	22 30	46 30	73 00	105 30	180 00					
20°	28 30	59 30	96 30	180 00						
15°	39 00	83 30	180 00							
10°	60 00	180 00								
5°	180 00									

Overturned Beds

Expressed in mathematical terms :—

$$\Theta = \beta + \gamma - 90 \mp \omega$$

Where : Θ = True original azimuth of the linear structure.
β = Observed azimuth of the dip of bedding plane.
γ = Observed pitch of the linear structure in the bedding plane, measured clockwise as seen from above.
ω = Correction factor (i.e. the amount the azimuth will be in error if the bedding plane is only rotated about the strike without taking the plunge of the fold into account).

The derivation of (ω) is given in section III.

The sign of the correction factor (ω) is determined as follows : When the plunge of fold axis is *away* from an observer on the crest of an anticline, for linear structures on the left-hand limb (+) ; for those on the right-hand limb (−). A syncline can be considered as two adjacent anticlines.

All these considerations apply equally well to overturned limbs, though in those cases the sign of (γ) becomes (−).

Table I demonstrates the following important points :—

(*a*) The magnitude of the error increases with larger amounts of dip and becomes considerable when beds are overturned.
(*b*) The magnitude of the error also increases with larger amounts of plunge.
(*c*) The error on the axial plane is nil.

For a large number of operations, Table II is suggested as a means of recording data :—

TABLE II.—SUGGESTED TABULATION FOR CALCULATION OF TRUE AZIMUTH

Type	β	γ	$\beta + \gamma$	-90	Dip	Pl.	$\pm$	ω	Result	Remarks
groove cast	144	151	295	205	65	25	—	15	190	
groove cast	002	88	90	360	48	25	+	10	10	

This method of plunge correction, although derived for similar folds, applies equally well to concentric folds. In the latter case, the particular locality on the limb on which the linear structure is situated can be regarded as part of a similar fold. The relationship between the plunge of the fold axis and the dip of the bedding plane will remain as before.

It must be stressed, however, that all plunge correction methods are based on the assumptions that :—

(*a*) folds are geometrically perfect bodies,

(*b*) non-plunging folds attained a plunge by rotation about a horizontal axis which is at right angles to the fold axis,

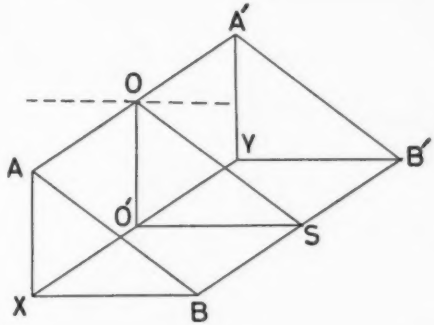
(*c*) no appreciable rotation of fault blocks have taken place about vertical axes,

(*d*) no distortion within the bedding plane has occurred.

To what extent these assumptions are justified in nature, will surely depend on individual cases.

III. Derivation of ω

In Text-fig. 1 let AA′XY and XYBB′ be two planes of reference, the former vertical and the latter horizontal ; let them meet in the line XY. Suppose the plane AA′BB′ is a bedding plane situated on the limb of a non-plunging anticline, the fold axis being AA′. Let a linear structure OS on this plane be perpendicular to the strike BB′, O being on AA′ and S being on BB′. It will be shown presently that this special case for OS is really part of a general case.



Text-fig 1.

If the bedding plane had been restored to horizontal by rotation about its strike, the direction of OS would have coincided with O′S where O′ is a point on XY, vertically below O.

Suppose the fold axis is now given an amount of plunge (ϕ) by rotation about a horizontal axis normal to AA′XY through O, so that $\widehat{POA'} = \phi$, P being on XY (Text-fig. 2). The linear structure will move to a position OT where T is a point on the horizontal plane XYBB′ (In orthographic projection the exact position of T can be established by remembering that $O'O : O'S = O''O : O''T = \cot \widehat{SOO'}$).

Now PT is the " new " strike. Let OW be the new dip and its, projection on plane XYBB′ be O′W. Let the amount of dip be (α)

i.e. $\widehat{OWO'} = \alpha$. Let the angle $\widehat{SO'W} = \lambda$, and $\widehat{TOW} = \rho$. If this bedding plane is restored to horizontal by rotation about axis which passes through O and is parallel to the strike PT (i.e. simple rotation method), the direction of OW will coincide with O′W and the direction of the linear structure will be O′T′ where $T'O'W = TOW = \rho$. So far the operation corresponds to

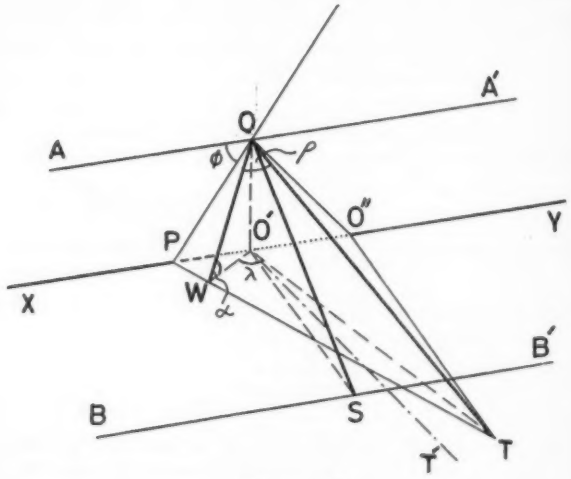
$$\beta + \gamma - 90$$

which has been illustrated in Wood and Smith (1958).

It can be seen that :—

(*a*) The amount of angular error between O′S (required true azimuth) and O′T′ (apparent " original " azimuth) is $\widehat{T'O'S} = \omega = \rho - \lambda$.

(*b*) The final effect of using simple rotation method without taking the plunge into account is an apparent rotation of the bedding plane



TEXT-FIG 2.

about a vertical axis. Therefore on this plane, any linear structure in any direction will need the same amount of correction as the particular one chosen as OS.

The value of (ω) is determined as follows :—

The right-angled triangles OTW, OTP have a common angle :—

$$\therefore \widehat{OPW} = \widehat{WOT} = \rho$$

Similarly $\widehat{O'PW} = \widehat{WO'S} = \lambda$

From the right-angle triangle, on the solid OO'WP, by sine rule :—

$$\sin \rho = \frac{\sin \phi}{\sin \alpha} \quad \text{and} \quad \sin \lambda = \frac{\tan \phi}{\tan \alpha}$$

Here $\omega = \rho - \lambda$ can be found in terms of (α) and (ϕ).

It can be verified that, in the case of overturned strata :—

$$\omega = \rho + \lambda$$

Various values of (ω) for given discrete amounts of plunge and dip have been calculated and presented in Table I.

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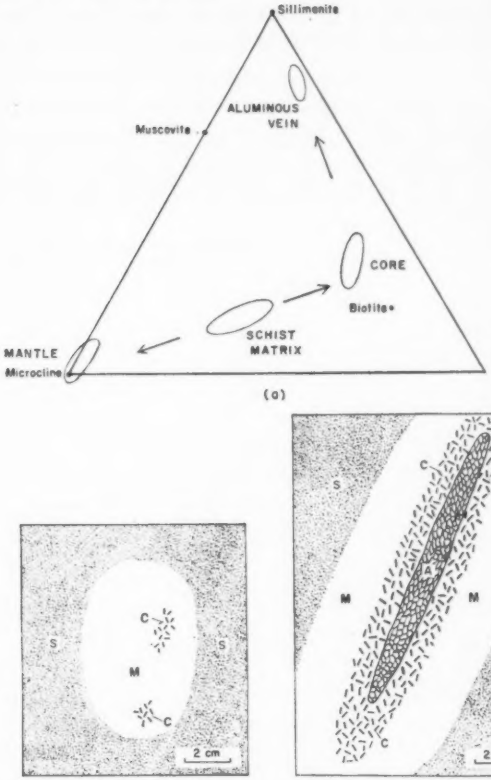
CORRESPONDENCE

METAMORPHIC SEGREGATION BODIES

SIR,—Structures similar to those described by Miss Knill (1959) have been reported from enclaves of metasediment in the South Savannas Granite of British Guiana (Barron, 1959). They show some additional points of interest and are briefly reviewed below.



S = schist matrix.
M = potassium-rich mantle.
C = core.
A = axial vein.

TEXT-FIG. 1

(a). AKF diagram showing differentiation trends.
(b). Normal segregation body in schist.
(c). Lenticular segregation in schist, with aluminium rich axial vein.

The structures occur in quartz-microcline-oligoclase-biotite schist, within a half-mile of the very extensive South Savanna biotite granite. In some of the more biotite-rich enclaves they closely resemble Miss Knill's examples both in size and in the relative proportions of core and mantle, but cordierite is absent while sillimanite in the mantle is accompanied by andalusite idiomorphs. Usually, however, the structures are larger—up to 10 cms. across—while the cores measure only one or two cms. in the largest examples. Quartz, plagioclase and iron oxide occur throughout core and mantle, and in the surrounding schist. In addition to these minerals the core usually carries coarse green-brown biotite and cordierite which is commonly poiciloblastic and appears to have replaced most of the original constituents of the rock. The mantle carries, on the contrary, no biotite, but abundant fresh microcline, which has usually induced an albite-enriched rim in the plagioclase in contact with it. In addition, muscovite, together with small granules of new quartz, appears to have been derived largely from the microcline in mantle and unaltered schist. The biotite of matrix and core is identical, and appears to have recrystallized last of all. Sillimanite is sometimes present, but in the core rather than in the mantle.

Nearer the granite, more aluminous segregations develop, at first as clots carrying quartz, cordierite, and sillimanite, and associated with the cores described above. These finally develop into lenticles carrying coarse quartz along the axis, with 10 to 15 per cent of sillimanite together with some cordierite and plagioclase. The margin carries the usual clot minerals—quartz, biotite, plagioclase with minor sillimanite, muscovite—and in addition some green chlorite.

The accompanying sketches and AKF diagram show the form of the structures and summarize the mineralogical trends involved in the differentiation into core and mantle, and in the later development of alumina-rich veins. There appears to have been no volume change, at least in the former, so that an overall access of potassium must follow from the small relative size of the core. The development of the veins likewise indicates an access of aluminium from outside the system.

I should like to thank Professor Deer for his kindness in enabling me to use laboratory and X-ray facilities in connection with the structures described.

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16th January, 1960.

IRISH EROSION SURFACES

Sir,—In the course of his study of altimetric frequency graphs, Mr. G. L. Davies (1958) has drawn attention to the similarities in the graphs, based on 20-foot groupings, for ten of the southern counties (Dublin, Wicklow, Wexford, Tipperary, Waterford, Cork, Kerry, Limerick, Clare and Galway) and the similarities in the graphs for ten of the northern counties of Ireland (Mayo, Sligo, Leitrim, Donegal, Tyrone, Londonderry, Antrim, Down,

Armagh and Louth). He has shown that maxima occur fairly frequently at certain heights and, he suggests, that this accordance is rather too frequent to be dismissed as mere chance. In fact, the occurrence and coincidence of peaks *can* be partly attributed to chance and, on a purely statistical argument, some of the erosion surfaces deduced from the altimetric frequency graphs are of very doubtful significance. Indeed, for the northern counties, they are clearly of no significance at all.

In order for the frequency in a group to be a maximum it must exceed the frequencies in adjacent groups. Thus, in order to determine the chance of a peak occurring it is necessary to look at the group frequencies in sets of three. If there are N groups altogether, the total number of sets of three is $N - 2$. In each set of three there are six possible permutations, of which two will have the highest value in the middle ; the probability of a peak occurring by chance in a set of three is, therefore, $\frac{1}{3}$. Thus, in a series of N groups the number of peak frequencies expected, by chance, is $\frac{1}{3}(N - 2)$. For each of the ten southern counties considered by Mr. Davies there are fifty-one groups, using the 20-foot groupings. The expected number of peaks in each county is, therefore, $\frac{1}{3}(51 - 2)$; that is, $16\frac{1}{3}$. In Table A the observed number of peaks is set out, together with a probability value which indicates the probability of the difference between the observed number and the expected number occurring by chance. For an N exceeding about ten, the probability distribution of peaks is approximately normally distributed about the expected number with a variance of $\frac{16N - 29}{180}$ (see Kendall (1955)). Only in the case of Dublin is the observed number of peaks associated with a very small chance probability ; for this county, therefore, there may be a systematic movement in the group frequencies associated with a theory of erosion surfaces.

For the aggregate 510 groups, adopting similar reasoning, the expected number of peaks is $169\frac{1}{3}$. The observed numbers are 156, in the southern counties, and 158 in the northern counties. The probabilities of these discrepancies occurring by chance are 0·0476 and 0·0910 respectively.

TABLE A.—SOUTHERN COUNTIES—NUMBER OF PEAK FREQUENCIES

County	*Observed Number of Peaks*	*Chance Probability*
Dublin	12	0·0340
Wicklow	15	0·5156
Wexford	18	0·4180
Waterford	13	0·1030
Tipperary	14	0·2542
Cork	16	0·8728
Kerry	17	0·7414
Limerick	19	0·1936
Clare	17	0·7414
Galway	15	0·5156

Apart from the actual number of peak frequencies, Mr. Davies has remarked on the occasions on which peak frequencies have coincided in the different counties. The number of coincident peaks, again taking the 20-foot groupings, is shown in Table B. Set against the observed numbers are the theoretical values which would be obtained if the coincidence of peaks is attributed purely to chance. These theoretical numbers have been computed using the binomial expansion $(p + q)^n$, where p is the probability of a peak frequency ($\frac{156}{510}$ in the case of the southern counties, $\frac{158}{510}$ in the case of the northern counties), $q = 1 - p$ and n is the number of counties in the group. The respective individual items in the expansion give the probabilities of 10, 9, 8, 7, etc., peaks coinciding by chance.

TABLE B.—DISTRIBUTION OF COINCIDENT PEAK FREQUENCIES

Number of Peaks Coinciding	*Southern Counties*		*Northern Counties*	
	Observed	*Expected*	*Observed**	*Expected*
10	—	0·0	—	0·0
9	—	0·0	—	0·0
8	1	0·1	—	0·1
7	4	0·5	1	0·6
6	5	2·0	3	2·1
5	3	5·6	6	5·7
4	3	10·5	10	10·7
3	12	13·6	12	13·6
2	10	11·6	10	11·3
1	7	5·8	7	5·6
0	6	1·3	2	1·3
	51	51·0	51	51·0

$\chi^2 = 12{\cdot}04$, for $n = 3$; $P = 0{\cdot}01$. $\chi^2 = 1{\cdot}42$, for $n = 3$; $P = 0{\cdot}70$.

(* These values have been deduced from the 40-foot groupings given by Mr. Davies in his Table II).

Adopting the customary χ^2 test for the significance of the difference between the observed and expected numbers, for the northern counties the difference is such as would occur by chance seventy times out of a hundred, if the true difference is zero, and is, therefore, clearly not a significant difference ; the implication is that, for this group, the erosion surfaces deduced from the altimetric frequency graphs are, on the basis of statistical theory, untenable. For the southern counties, chance will only explain the difference once in a hundred times and, for this group, therefore, it seems likely that some factor, other than chance, is required to explain the coincidence of peak frequencies in the graphs.

Mr. Davies concludes his analysis by suggesting that the occurrence at certain heights of peak frequencies in the southern counties is matched by peak frequencies, some 20 feet higher, in the northern counties. Using his Table III and lagging the northern frequencies by one 20-foot group the following table may be derived.

TABLE C.—COMPARISON OF MAXIMA IN SOUTHERN AND NORTHERN COUNTIES

Occurrence			
Southern	*Northern*	*Observed*	*Expected*
Peak	Peak	8	5·2
Peak	No peak	8	10·8
No peak	Peak	8	10·8
No peak	No peak	25	22·2
		49	49·0

$\chi^2 = 3{\cdot}32$, for $n = 3$; $P = 0{\cdot}35$.

Here again, the expected numbers have been calculated using a binomial expansion, with $p = \frac{1}{6}$, $q = 1 - p$, and $n = 2$. The value of χ^2 is not significant ; it would occur by chance thirty-five times out of a hundred if the true value is zero—that is, if there is no real difference between observations and expectation. The theory of a parallel pattern of peak frequencies in the southern and northern counties cannot, therefore, be sustained by a statistical argument.

These conclusions are largely of a negative character. In the absence of

extensive field studies it is not possible to say whether or not the apparent fruitlessness of Mr. Davies' statistical analysis is borne out by research in the field, but he does remark that he can find little support from field mapping of erosion surfaces in County Down and County Clare.

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19*th May*, 1960.

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PETROGRAPHY OF THE MESOZOIC SUCCESSION OF SOUTH WALES

SIR,—In his account of the petrography of the Mesozoic succession of South Wales, Dr. C. B. Crampton (*Geol. Mag.*, 1960, xcvii, 227) concludes that " derivation of material . . . was very local . . . Thus the mineral assemblage at any particular point in the littoral zone was determined largely by the nature of the outcropping rocks of the coastal mainland. This is particularly evident within the Rhaetic sandstones ". The statement is based, in part, on evidence advanced to suggest that garnet appears only in the sandstones near contemporaneous shore-line outcrops of Old Red Sandstone and is contrary to some of my own findings (*Proc. Geol. Assoc.*, 1959, lxx, 158–178) which may not have been published in time for Dr. Crampton's prior consideration.

Among these findings is the recognition of two sandstones separated by black shales. The Lower Sandstone everywhere (even as far west as Pyle, several miles from any possible outcrop of Old Red Sandstone) contains garnet in such abundance as to be almost diagnostic whereas in the Upper Sandstone that mineral is scarce or even absent. The distribution of garnet thus varies with horizon rather than with shore-line outcrop as claimed by Dr. Crampton; indeed his garnet-free Sample 4 (Table I) must be presumed to belong to the Upper Sandstone since I have collected garnetiferous Lower Sandstone in the Cwrt Colman Railway Cutting, only 600 yards to the east of the quoted map reference. Although I have not examined by microscope any samples from Dr. Crampton's other three named localities it seems that the two without garnet (No. 5 and the one from St. Mary Hill) also belong to the Upper Sandstone since the Lower is overlapped thereabouts; the garnetiferous Specimen 3, on the other hand, is part of the How Mill-Herbert's outcrop which I have tentatively correlated with the Lower Sandstone (*op. cit.*, 168).

Nevertheless, there may be local concentrations of minerals as evinced by the titaniferous suite in Sample 4 and in my own record of a " flood " of apatite in the Upper Sandstone at Bridgend, but if the distribution of garnet is any guide, such concentrations could only be proved to be local by widespread sampling of specific horizons within the sandstone concerned. This is rarely possible because of the difficulty of identifying specific horizons. At almost every horizon within the Rhaetic sandstones, moreover, quantitative examination is complicated by the presence of yellow or colourless fossil phosphate which forms part (often a very large part) of the heavy fraction in bromoform separations and which occurs either as sub-angular to sub-rounded grains simulating detrital minerals or as recognizable fragments of fish tooth, scale or bone.

Finally, the Rhaetic sandstones have often been described as estuarine, and apart from the caution expressed by Strahan (1904, The Country around Bridgend, *Mem. Geol. Surv.*, 36) no evidence has yet been produced to the contrary or to support Dr. Crampton's claim of " little detritus being carried from inland regions by large rivers ".

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Sir,—We write to deplore the misleading practice of describing as petrography mere accounts of the heavy mineral content of sedimentary rocks. For instance, Mr. C. B. Crampton's recent paper (" Petrography of the Mesozoic Succession of South Wales ", *Geol. Mag.*, 1960, xcvii, 215–228) deals with the number-frequency of heavy minerals, but gives no petrographical details of the rocks in which they were found. The description of sedimentary rocks as *rocks* is surely a well-established branch of petrography and deserves better than to be confused with a tabulation of mineral species.

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15th July, 1960.

REVIEWS

Mineralogy—Concepts, Descriptions, Determinations. By L. G. Berry and Brian Mason. pp. xi + 612, numerous text-figs. and photographs. San Francisco: W. H. Freeman and Co. (London, W. H. Freeman and Co., Ltd.), 1959. Price 56*s*.

Part 1 (Concepts) contains 275 pages distributed in the following chapters: Introduction, 11; Crystallography (i.e. Crystal Geometry and Symmetry), 138; Chemistry of Minerals, 34; Physics of Minerals (i.e. Notes on Simple Physical Properties), 25; Genesis of Minerals, 41; Determinative Mineralogy, 20; Systematics of Mineralogy, 5. The subject of the optical properties of crystals is specifically excluded.

Part 2 (Descriptions) contains 287 pages in which some minerals are described in a simple chemical classification, with structural sub-divisions for the silicates. The data given are: formula, crystal system, and class; axial elements; cell dimensions; common forms and angles; followed by the usual tests on hand specimens, with notes on diagnostic features, chemistry, occurrence and uses. For the silicates the general structural relations are given, and there are notes on the simpler structures of other minerals.

Part 3 (Determinative Tables) contains 29 pages in which minerals are listed by observations on hand specimens, along with simple physical and chemical tests. The determination of minerals by their optical properties is regarded as outside the scope of the book.

In a text-book there are three factors: first the subjects chosen (and those omitted), second the manner in which the topics are discussed, and third the general balance of the book. The omission of the optical properties of the transparent minerals is surprising in a text-book of this quality, but the presentation of the material is excellent. In chapter 2 the approach is through the lattice concept, while the stereogram and the international symbols of crystal classes are used. This chapter demonstrates that, properly done, the modern treatment simplifies the whole teaching of the symmetry and geometry of crystals. Likewise, in the chemical chapters the modern approach is very

well done; the concepts of crystal chemistry are used throughout, and analyses are tackled from the start. The chapter on mineral genesis is a model introduction to this subject.

It is, however, on the balance of the book that criticism is likely to be made. The Preface states that " This book is designed to satisfy the requirements of an undergraduate course in mineralogy. It is intended not only for the student who will later take more advanced work in the subject, but also (and perhaps more so) for the student for whom this is not the first but also the last course in mineralogy ". In the opinion of the reviewer it is hard to conceive of a course in which the geometry and symmetry of crystals part would be carried to the level reached in this book without the students being taught to identify the transparent minerals by means of their optical properties.

N. F. M. H.

GEOLOGIC EVOLUTION OF EUROPE. By ROLAND BRINKMANN (translated from the German by John E. Sanders). 161 pp., with 46 figures, 19 plates and 18 correlation charts. Ferdinand Enke Verlag, Stuttgart, 1960. Price: Paper 52*s*. 6*d*.; Cloth 60*s*.

Many University teachers, familiar with the difficulty of persuading students to read in any language other than English, will welcome this book as a simple introduction to European stratigraphy. It is a translation of part of Professor Brinkmann's two-volume work and is aimed at a fairly elementary audience.

Each geological system receives similar treatment—a general introduction; an account of its development in the principal regions in which it occurs; a summary of its general features in terms of climate, earth movement and igneous activity; and a short list of references. There is also a detailed correlation table for each system, illustrations of common fossils, many palaeo-geographical maps and other line diagrams. Most of these seem to be taken directly from the parent work, with the addition of explanations in English. The correlation tables remain in German.

The difficulties of selection and compression involved in writing an account of the geological evolution of Europe in 161 pages are enormous. The Ordovician of Norway and Britain together, for example, is allotted less than one page of print. In spite of these difficulties, however, it can fairly be said that the book provides the beginner with a broad picture into which he can subsequently build more advanced stratigraphy. It also gives him, in the form of detailed correlation tables, some material for this latter purpose.

The style of English, due to Dr. J. E. Sanders, is one of crisp, short sentences which will commend itself to most readers.

W. W. B.

BRITISH CAENOZOIC FOSSILS (TERTIARY AND QUATERNARY). British Museum (Natural History), pp. vi + 130, with coloured map and 44 pls. 1959. Price 6*s*.

This admirable handbook is the first of a small series illustrating British fossils. The text is brief, and apart from plate explanations comprises simply a stratigraphical table and faunal lists of successive horizons, with a note on zoological nomenclature. Three hundred and fifty-four species are illustrated on 44 plates by the excellent line-drawings of the late Mr. A. G. Wrigley, supplemented and completed by Miss Buswell and Miss Ripley. The aim was to provide a means for amateur collectors to identify their own material, but the price is so reasonable as to prompt the fear that students generally will be tempted to possess themselves of these handbooks and neglect to produce any drawings of their own.

O. M. B. B.

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